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Vol. 1, No. 1
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Characteristics of 'Adders' in Proportional Reasoning

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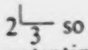
ABSTRACT

Adders are students who consistently use the incorrect-addition strategy on 'hard' ratio items. In order to investigate their errors and strategies on ratio tasks, 33 Taiwan adders were interviewed. Unlike English adders who use addition-based methods on easy ratio items, the Taiwan adders use multiplicative algorithms predominantly on these items. In order to provide a fuller description of adders' characteristics, some aspects, such as awareness of non-integer multiples, the use of fractions and decimals, awareness of both within and between ratios, and distinguishing non-ratio contexts from ratio contexts, were investigated. As a result, some characteristics of Taiwan adders and English adders are compared in this paper.

Key words: misconception, ratio and proportion, errors analysis

I Introduction

1. The Incorrect Addition Strategy

When asked to enlarge the figure 

so that the new base line is 5 units, a child concentrating on the difference 5-3 rather than 5/3 will say: "5 is 2 more than 3, so the new upright is 2 more than 2, answer 4 units". Such a strategy for solving proportional items is called the *incorrect-addition strategy*.

Piaget and Inhelder (1958) describe the incorrect-addition strategy as a typical answer from a child at the late concrete stage. Karplus *et al.* (1975) and Hart (1984) see it not as an inevitable consequence of developmental level but as a method which should be corrected. The frequency of the incorrect-addition strategy among early adolescents has been proved to be dependent on the setting of the tasks. For example, the incidence of this procedure was high on the lemonade puzzles (Karpluss *et al.*, 1983a) and on the Mr Short task (the missing value paper clips task) (Karplus and Peterson, 1980; Hart, 1981), in both of which the rates were dimensionless; the incidence of this procedure was low on 'rate' problems in which the rates had dimensions (i.e., ratios with denominator numbers, such as speed, density and unit prices) (Vernaud, 1980, 1983; Ruply, 1981; Karplus *et al.*, 1983b). In relation to these studies, Karplus *et al.* (1983b) concluded that "the occurrence of dimensions inhibits the (incorrect) addition strategy".

Both Hart's (1981) CSMS ratio study and its replicated study in Taiwan (Lin *et al.*, 1985, Lin K.H. *et al.*, 1986) aimed to present pictures of children's mathematical understanding which were representative of the English and Taiwan child population, respectively. The CSMS ratio work is described in detail elsewhere (Hart, 1981). Briefly, a 'test of understanding' of ratios comprising more than twenty items was administered to a large sample of students, 2257 in the CSMS study and 3098 in the Taiwan study (see Hart, 1981; Lin, 1988 for details, respectively). On the basis of the results obtained, a hierarchy of four levels of understanding was described, with the lowest level of understanding being designated 'Level 1' and the highest level 'Level 4'. Students who did not achieve criterion performance on the items assigned to level 1 were described as performing at level zero. In the case of the U.K.study, a significant feature of the performance of children operating at the lower levels of understanding was their use of the incorrect addition strategy (Hart, 1981, 1984). Consequently, it became a matter of interest to examine the role of this strategy in the case of the students in the Taiwanese study. This paper, therefore, sets out to examine the prevalence and context of this strategy within the Taiwanese sample.

2. *Definition of 'Adders'*

In the CSMS study, the incorrect-addition strategy occurred most frequently on the items shown in Table 1. All four items concerned enlargement of figures and ratios which were dimensionless (Karplus *et al's* (1983) language). These items will be called the addition-type questions.

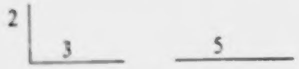
Table 1. The addition-type questions

1)Mr Short question (adapted from Karplus, 1975). Given a picture to show Mr Short's height is 6 paperclips. When we measure Mr Short and Mr Tall with matchsticks:

Mr Short's height is 4 matchsticks.
Mr Tall's height is 6 matchsticks.

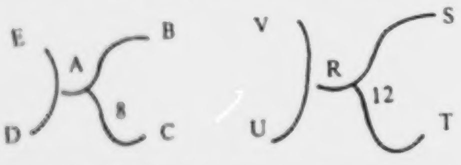
How many paperclips are needed for Mr Tall's height? Error answer: 8.

2)Geometric enlargement question.



Error answer: 4

3)Geometric enlargement of K-shape question.



a)AB is 9, how long is RS? Error answer: 13
b)UV is 18, how long is DE? Error answer: 14

These items also attracted the incorrect-addition strategy in the case of the Taiwan sample, although the percentage of students using this strategy in the latter case was typically less (see Table 2 for a comparison of the CSMS and Taiwan data).

Table 2. Incidence of error answers (%)

Item	CSMS study (1976 data, N-2257) (age 13-15)	Taiwan study (1985 data, N-3098) (age 13-15)
(1)	47.4(32)•	24(50)
(2)	42.3(12.5)	23(24)
(3a)	39.6(20)	34(29)
(3b)	29.1(21)	27(32)

• number inside each bracket denotes the percentage of correct responses.

Hart (1981) described those students who consistently used the incorrect addition strategy to solve at least three out of the above four items as " *adders* ". With the same identification process as Hart, we identified 302 Taiwan 'adders' from the students (n-1599) in our longitudinal study (Lin *et al.*, 1986). Among these 302 Taiwan adders, the incidence of incorrect-addition strategy on the four addition-type questions was (1) 74%, (2) 57%, (3a) 99%, and (3b) 96%. For English adders, the highest incidence is for the Mr Short question (ref. Table 1 and Hart, 1984). Although the incidence of the incorrect-addition strategy depends on the setting of the task, this dependence seems to have a culture-related component.

In both English and Taiwan studies it was found that 'adders' are not in any particular age group, as Table 3 shows (Hart, 1984; Lin *et al.*, 1986).

Table 3. Percentage of adders in each age group

Age	CSMS (n-2257)	Taiwan (1986 data, n-1599)
13	246/800-30.7%	•
14	220/767-28.7%	162/774-20.9%
15	156/690-22.6%	140/825-17%

• The 1986 data included students who were in the 1985 data and took the same test after one year, so there were no 13-year-old students. These data do indicate, however that there are 5 - 8% more English adders than Taiwan adders in each age group.

3. *Characteristics of the CSMS 'Adders'*

In order to develop appropriate diagnostic teaching procedures, it is necessary to understand why 'adders' make this kind of error. Consequently, Hart (1980a,b, 1981, 1984) investigated the performance of 'adders'

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in the CSMS study in detail. According to her findings, these students used the additive methods consistently on ratio problems. Where the relationship between the values involved was simple (such as double, half, three times, etc.), the students were able to use their additive methods to obtain a correct solution. Difficulties arose when the numerical relationship were more complex. In these cases, the 'adders' were not able to apply their methods correctly. Instead, they resorted to a simple addition of the given values, giving rise to the 'incorrect-addition strategy'. In general, the adders' approach was characterised by

a) using addition-based child-methods, such as halving, doubling, adding on and building up to solve easy ratio items;
b) avoiding application of multiplication of fractions, and taught algorithms; and
c) never using multiplicative strategies, such as the unitary method (how much for one), and the formula method ($a/b = c/d$).

In fact, it seems that the CSMS adders were working only within the addition system. They are really 'adders' in the true sense of that word.

Data from the 302 Taiwan adders (Lin *et al.*, 1986) showed that 36 of them displayed understanding at level three. Examining the test papers of these level three adders, we found that they were using multiplicative strategies successfully on easy items and using the incorrect-addition strategy as a fall-back method for the addition-type questions.

The question this provokes is: are the characteristics of Taiwanese adders similar to those of the CSMS adders? In order to examine this question, the following investigation was conducted.

II. Methodology

1. Sample

A sample of 33 adders, aged 13-14, was identified from six classes in three typical schools in Taiwan. These were chosen to give a similar distribution of level of understanding to the SESM study (Hart, 1984), with the addition of five more students at level three in order to learn more from this level group. Table 4 shows their level of understanding ratio as identified by the adapted CSMS test. Table 5 shows the incidence of the incorrect-addition strategy used by these adders on the addition-type questions.

Again, Table 5 shows the highest incidence of the incorrect-addition strategy on the enlarged curved K-shape question.

Table 4. Performance of the adders n=33

Level	0	1	2	3
Number of adder	2	14	11	6

Note: Level 4 items are those in which the incorrect-addition strategy occurs.

Table 5. Incidence of the incorrect-addition strategy n=33

	1. Mr Short	2.Enlargement	3.Enlargement	
	4:6 = 6:x	L-shape	K-shape	
		3:5 = 2:x	(a)8:12 = 9:x	(b)12:8 = 18:x
Number (%)	25(75.7%)	25(75.7%)	33(100%)	32(96.9%)

2. Interview

Each of these adders was interviewed for about 30-40 minutes during the same week that the written test was given. On interview, each one was shown the test paper completed earlier, and asked to explain the answers to some items they had completed. Since the question under examination was whether Taiwanese adders' performance is characterised by the same features as the CSMS adders' performance, students were interviewed on selected 'easier' items where correct answers could be found by additive methods, as CSMS adders did, as well as on the addition-type questions. This was necessary in order to determine if the items which they had answered correctly had also been handled by additive methods. The 'easier' items selected for use in the interviews are outlined in Table 6.

Following students' explanations and bearing in mind the features identified for the CSMS adders, the interviews focused on investigating the following questions:

a) Do 'adders' ever use multiplicative strategies?
b) How did adders decide to use either an additive or a multiplicative strategy?
c) Are adders aware of non-integer multiples?
d) What kind of understanding of fractions do 'adders' have?

In order to provide a fuller description of adders' characteristics, the following two aspects which were not covered in Hart's (1981, 1984) studies were also examined:

e) Are adders aware of two kinds of ratios; a ratio of two portions either within one figure or between two figures?

f) How good is adders' recognition ability for distinguishing non-ratio contexts from ratio contexts?

Table 6. The easy items

1 The recipe question (four items)
Onion soup recipe for 8 persons,
2 pints of water, 4 chicken soup cubes, . . .
the amounts required for 4 persons and 6 persons.
2 a)The snake-egg question (adapted from the ell-sprat question in the CSMS version)(four items)
b)The eel-earthworm question (adapted from the eel-fishfinger question in the CSMS version) (four items)
The snake/eel questions concerned the amounts of food (i.e., egg, which is a discrete object in 2a and earthworth, which is a continuous quantity in 2b) which were given to snakes/eels of different lengths, the amount being proportionate to the length of the snake/eel.
3 The rectilinear enlargement question (two items) (base,upright) : (4,2) vs. (8,x) and (3,2) vs. (6,x).

III. Findings

1. Methods used by Taiwan adders on 'easy' items

Unlike the CSMS adders who used only addition-based methods on the easy items, the Taiwan adders used predominantly multiplicative methods on these items.

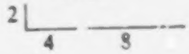
Being able to cope with these easy items is the criterion for a student to display understanding at level three. The six level three adders in the interviews, out of 33, used multiplicative methods successfully on these easy items. Two of them used the formula method consistently.

We will, therefore, focus in the rest of this section (III.1) on the other 27 adders who displayed understanding at a level below three. These students are likely to provide us with more interesting data. Table 7 shows the incidence of the multiplicative methods used by these students.

i) Correct multiplicative strategies

Comparing the numbers in columns C and CM in Table 7, we observe that most of the correct responses were based on multiplicative methods (except item 1(2) and 2a(1)).

Table 7. Incidence of multiplicative algorithms N-27

Item/Number structure	C	CM	M
1. The recipe question			
(1) 8 : 4 = 2 : x	24	19	22
(2) 8 : 6 = 2 : x	13	5	17
2a.The snake-egg question snakes 5, 10, 15 feet			
(1) 5 : 10 = 2 : x	24	13	15
(2) 10 : 15 = 12 : x	15	15	19
(3) 15 : 10 = 9 : x	13	10	13
2b.The eel-earthworm question eels 10, 15, 25 cm.			
(1) 10 : 25 = 2 : x	8	6	20
(2) 15 : 25 = 9 : x	4	4	14
(3) 25 : 10 = 19 : x	7	6	13
3. The rectilinear enlargement find the upright			
(1)  2 4 8	23	22	22
(2) 2 3 6	15	14	18

C denotes number of correct responses, including additive, multiplicative and others.
CM denotes number of correct multiplicative responses.
M denotes number of multiplicative responses, including correct and incorrect.

In the recipe question 1(1), where the amount for 8 people was given and the amount for 4 people was required, 17 adders concentrated on the 'multiple' relation of 8 and 4. These students used the ***multiplier method***. Two adders solved the problem by first finding the amount for one person. They were using the *unitary method*. Some adders used both methods, apparently choosing the more economic one in the given situation. For example, in the snake-egg question 2a(1), finding the multiple relation between the length of snakes (given as 5 feet and 10 feet) was easy, and all the 13 correct multiplicative responses used the

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multiplier method. However, in item 2a(2), finding the multiple relation between the length of snakes where these were 10 feet and 15 feet was relatively more difficult than finding the unitary amount (5 feet as a unit). In this case, 10 of the 15 correct multiplicative responses used the unitary method and 5 used the multiplier method.

ii) Incorrect multiplicative strategies

In Table 7, M-CM denotes the number of incorrect multiplicative responses. Although these adders did think of multiplying, they didn't always know what to multiply.

Two different types of incorrect multiplicative strategies were observed in the interviews, namely 'bigger/smaller so then multiplying/dividing' and 'undirected manipulation'.

The adder faced with an enlargement feels that multiplication/division is appropriate. However, the multiple/divisor used is not the enlargement factor, but is very often a small integer. The adder was using the *'bigger/smaller so then multiplying/dividing'* strategy and explained it in such a way in the interview. Table 8 shows the incidence of this strategy.

Table 8. Incidence of "bigger/smaller so then multiplying/dividing" N-27

Item	Algorithm	Number of adders used algorithm
2b(the eel-earthworm)		
(1) 10 : 25 = 2 : x	・2×2=4	2
	・2×2×2=8	2
	・2×2×2×2=16	1
	・2×3=6	2
	・2×4=8	1
	・2×15=30	1 Total 9
(2) 15 : 25 = 9 : x	・9×2=18	2
	・9×5=45	1
	・9×10=90	1
	・3×2×4=24	1 Total 5
(3) 25 : 10 = 10 : x	・10÷2=5, 5÷2=2.5	2
	・15cm=10cm, 5÷10=0.5	1
	・10÷3=3.3 (sharing)	1
	・25÷10=2.5, 10÷10=1	2 Total 6

The adder faced with a ratio item recognizes the need to operate multiplicatively and attempts to do so. However, there appears to be little idea of how to reason proportionally and to use the data, and so the adder manipulates either all three given data in two procedures, similar to the two correct multiplicative procedures, or two of the three given data in a procedure(s), until an answer is obtained that seems reasonable. The adder is doing *'undirected manipulation'* (this term is adapted from Chick et al., 1987; see table 9).

iii) Correct additive strategies

In Table 7, C-CM denotes the number of adders who used the *building up* strategy, such as repeated addition or adding on extra units according to the multiple, on each item, except 2a(1) where two responses used the 2's pattern, i.e., 2,4,6. Table 10 shows some algorithms for this strategy.

The building up strategy used by Taiwan adders on these items was similar to that which most of the English adders used. A slight difference was that the Taiwan adders did explain that 'a half' was 'dividing by two', whereas the English adders said there was no relation between 'halving' and 'dividing by two' (Hart, 1984).

iv) Incorrect additive strategies

On the snake-egg and the eel-earthworm questions, some adders kept carrying the data given in the first item 2a(1)/2b(1), i.e., 2 eggs for a 5 ft snake/2 cm earthworm for a 10 cm eel, to the rest of items, and reasoned that to each 5ft/10cm bigger (smaller), it was necessary to add (subtract) these 2 units. These adders were using the *'adding on/subtracting two'* strategy. The number of adders who used this strategy on item (2a(2), (3); 2b(2), (3)) was (6,7; 4,1), respectively. Note that the 6 and 7 adders who used this strategy on item 2a(2) and (3), respectively, were among the 9 adders who used the 'building up' strategy on item 2a(1) successfully. These adders, therefore, did behave like CSMS adders on the snake-egg question.

The adder faced with an enlargement felt that some extra units were needed to add/subtract for a bigger/smaller one. The number of extra units can usually be identified from the context, but sometimes can be arbitrary. The adder was using the *'bigger/smaller so then adding/subtracting'* strategy. The incidence of this strategy on the item (2a(1), (2), (3); 2b(1), (2), (3)) was (1, 2, 2; 4, 5, 7), respectively.

Adders who used the 'bigger/smaller so then adding(multiplying)/subtracting (dividing)' strategies were only concentrating on the *individual* data given in the context and were not aware of the need for a *relation* between data. Their incorrect strategies were rather naive and elementary.

On the eel-earthworm question, where the length of both eel and earthworm were measured in centimetres, three adders felt it was appropriate to use an additive

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Table 9. Incidence of "undirected manipulation" N=27

Item	Algorithm	Nunber of adders used algorithm
2a (the snake-egg)		
(2) $10 : 15 = 12 : x$	· $10 \times 12 = 120,\ 120 \div 15 = 8$	1 Total 1
(3) $15 : 10 = 9 : x$	· $15 \div 9 = 1\frac{2}{3},\ 1\frac{2}{3} \times 5 = 8\frac{1}{3}$	1
	· $15 \times 9 = 145,\ 145 \div 10 = 14.5$ Ans.15	1 Total 2
2b (the eel-earthworm)		
(1) $10 : 25 = 2 : x$	· $10 \div 2 = 5$	2
	· $2 \div 5 = 0.2$	1 Tutal 3
(2) $25 : 25 = 9 : x$	· $1\frac{2}{3}$ = 1cm eel, $1\frac{2}{3} \times 25 = 41$	1
	· $15 \div 9^{\bullet} = \frac{15}{9} = \frac{3}{5},\ 25 \times \frac{3}{5} = 15$	1
	· $15 \div 9 = \frac{15}{9}$	1
	· $25 - 15 = 10,\ 15 \div 5 = 3,\ 9 \div 3 = 3$ $10 \div 2 = 5,\ 5 \times 3 = 15$	1 Total 4
(3) $25 : 10 = 10 : x$	· $\frac{25}{10} = \frac{5}{2},\ \frac{5}{2} \times 10 = 25$	1
	· $25 - 10 = 15,\ 15 \div 3 = 5$	1
	· $25 - 15 = 10,\ 10 \div 2 = 5$	1 Total 3

• shows a typical error.

algorithm, e.g., on item 2b(2) with number structure 15:25=9:x, two adders gave 25-9=16 as the answer, and one adder used the following procedure:

15-9=6, 6+3=9, 9+3=12, Ans. 12.

Also, even on the 'easy' items some adders could not use correct additive methods, but resorted to the *incorrect-addition strategy*. Indeed, there are 3 and 6 adders who used this strategy on the rectilinear enlargement question 3(1) and (2), respectively. Three of them consistently used it on both items.

v) The consistency

Only one adder never used a multiplicative strategy on the easy items. Four adders used additive strategies on ten or more items (out of fourteen, four of them are not included in Table 7).

Twelve adders consistently used multiplicative algorithms before they faced the four addition-type questions. Six of them used correct multiplicative strategies consistently.

The other ten adders used approximately the same number of additive and multiplicative strategies on these easy items.

Table 10. Incidence of building up strategy N=27

Item	Algorithm	Number of adders who used algorithm
1 (1) $8 : 4 = 2 : x$	$2 - 1 = 1$	5
(2) $8 : 6 = 2 : x$	$1 + 0.5 = 1.5$	5
	$2 - 0.5 = 1.5$	1
	$2 \div 2 = 1,\ 1 \div 2 = 0.5$, Ans 1.5	2
2a (1) $5 : 10 = 2 : x$	$2 + 2 = 4$	9

The behavior of those Taiwan adders who were consistently using a multiplicative strategy on all the easy items was unlike that of the CSMS adders, for whom it was a case of 'what would be the most useful thing to do here?' (Hart, 1984, p.24). In fact, Hart (1984, p.23-24) says, "No child . . . used the same method throughout to find the solutions to these ratio

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and proportion problems."

In handling the taught multiplicative algorithms, most of the Taiwan adders behaved very differently from the CSMS adders, who only used addition-based methods. Indeed, Hart (1984, p.23) reports that "there was no evidence of teacher-taught algorithms at all."

2. *Methods Used on the Addition-type Questions*

The four addition-type items (ref. Table 1) concerned enlargement of figures, where the ratios were non-integer and dimensionless.

The incidence of use of the incorrect addition strategy by these 33 Taiwan adders is shown in Table 5, and is reinforced by the interview data.

There were eight responses which were different from the incorrect addition strategy on both the Mr Short question and the rectilinear enlargement question with an enlargement factor of 5:3. Five of them were ocrrect multiplicative methods on each of these two items. One adder used the formula method on the Mr Short question, and another one used it on the rectilinear enlargement question. The other three incorrect responses on each of these two items were similar to what we have described in the above section.

In this section, we will discuss how adders came to choose the incorrect addition strategy.

i) Choice of addition/subtraction

The five adders who consistently used the additive methods on most of the easy items, used the incorrect-addition strategy on all the addition type questions. How did they make their decision to use addition/subtraction?

Four of them were interviewed about this question.

(I: Interviewer; B: the adder B)

B: "No, this is not a problem of multiplication/division (the K-shape question)."

I: "Which kind of problem is a multiplication/division one?"

B: "It needs words like 'multiple' 'how many times' or 'sharing' etc."

I: "Could you give an example?"

B: "One pencil costs 12 dollars, how much do three pencils cost?
One cake shared by n people . . ."

Not only on the addition-type questions but also on the easy items, all four adders explained that their choice was based on the lack of certain *key words* in the problem sentences, similar to what adder B said.

ii) Reasons for switching to the incorrect addition strategy

Adder Xu, who consistently used the formula method on the easy items and the Mr Short question, did use the formula method on the rectilinear enlargement (factor 5:3) question but crossed the answer out and used the incorrect addition strategy as a fall-back method. In the interview, she explained:

". . . same shape means enlargement, I thought. However, here the enlargement factor was not 1, 1.5 or even 2. Nobody could enlarge a diagram 1.666 . . . times."

Xu's strategy was interrupted by the geometric setting and the complexity of its number structure.

When adders, especially those who consistently used a multiplicative strategy, attempted to solve the addition-type question, their planned actions were blocked or interrupted, due to the complexity of its number structure or its geometric setting (the context). McLeod (1986) points out that "the interpretation of that interruption is based on the student's knowledge, beliefs and previous experiences." Although the outcomes of adders' interpretation were the same, i.e., using the incorrect-addition strategy, the spontaneous reaction to that interruption by an individual adder differed. This difference was investigated in the interviews. The reasons for the difference lie in both cognitive and affective domains.

Firstly, with the exception of a half, the students' non-awareness of a non-integer multiple *as* a multiple was proved, in the interviews, to be the main reason why most of the Taiwan adders switched their correct multiplicative methods to the incorrect addition strategy. Some further discussion will take place in the next section.

Secondly, 25 adders out of 33 consistently used the incorrect-addition strategy on the three addition type of geometric enlargement items. Therefore, apart from the complexity of the number structures, the geometric settings might also create obstacles. Here is an example:

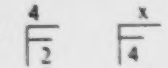
S: ". . . same shape just means the length of a bigger diagram is increased, so I add . . ."

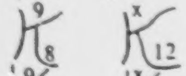
Adder S, who displayed understanding at level two and used decimals consistently to present the results of her multiplicative algorithms, interpreted 'same shape' inappropriately.

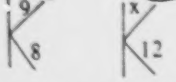
Thirdly, almost all Taiwan adders were using the incorrect-addition strategy on the enlargement of the K-shape question. Compared with the enlargement of the rectilinear L-shape question, the level of difficulty of the number structures of the two questions was not very different. So, the curved setting of the K-shape question was again a possible distractor.

In fact, three out of the six level three adders were unsure about the applicability of a ratio to curves which they had met for the first time.

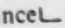
This excerpt showed that adder Wang had changed her incorrect-addition strategy to a formula method when the K was drawn using straight lines.

I:  Wang: "$\frac{4}{2}=\frac{x}{4}$"

I:  Wang: "x=13"

I:  Wang: "$\frac{9}{8}=\frac{x}{12}$"

Another two adders' excerpts were as follows:

> Guo: ". . . straight, can use ratio. Curved, I am not sure if I can use ratio.
> In a flash, I saw the relation of constant difference, I decided to use it."
>
> Jian: ". . . all items were using multiple relation before (on this test); the test paper might have a *trick*, it is impossible that each item was 'multiple'. I had such an experience before. Since  and *look different*, I changed my method."

Both Guo and Jian were distracted by the curve. Jian interpreted this distraction in terms of his belief about test papers, which developed from of his previous testing experiences. This example draws our attention to the affective aspect of choice of strategy. Taiwan junior high school mathematics classes are over tested. Very often students are trained to solve problems as quickly as possible. So, three adders out of the six level three adders were aware that multiplication is appropriate for the addition-type question. However, because subtraction was quicker and easier, they chose it, as Jian said in the interview:

> Jian: ". . . during the examination, I tried to choose between subtraction and multiplication. Subtraction was easy. I checked the answer, both with constant difference of 4 units (the K-shape item). It was right, so I chose subtraction."

Adder Jian even evaluated and felt happy about his choice, for he had been reasoning 'logically'.

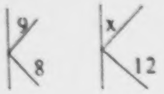
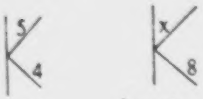
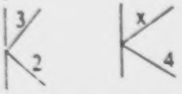
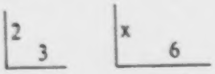
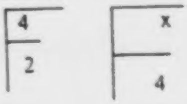
Although both the Taiwan adders and the CSMS adders largely used the incorrect-addition strategy on the addition-type questions, the descriptions in this section showed that the reasons most of the Taiwan adders came to use the strategy were different from the CSMS adders. On the geometric enlargement questions, Hart (1984, p.23) says "the children's answers . . . provided a clear indication that multiplication was not used to produce an enlargement. The children stated that the only way of obtaining 12 from 8 was by addition. "So, for the CSMS adders, the geometric enlargement questions seemed to be '*natural*' addition-type questions.

3. Additional Findings

Some aspects which extend beyond the ratio test paper were also examined in the interviews.

i) Awareness of non-integer multiples

In the interview, adder J was asked to solve a sequence of geometric enlargement items one by one, as follows:

Item	Response
(1) 	J: "x=13".
(2) 	J: "x=9".
(3) 	J: "x=5".
(4) 	J: "x=4, 4=2×2".
(5) 	J: "x=6. Because 4 is 2 times of 2, so 4+2=6. Oh! No! It should be 4×2=8".

Responding to this recognition, i.e., seeing the relation between 'multiplier' and 'multiplication', adder J then went back to correct the solutions of items (3) and (2), but still kept 13 as the answer to item (1).

> I: "Don't you think these three items of K-shape are similar?"
>
> J: "They are similar, but there is no multiple relation between 8 and 12."

Adder J's response was typical of students who were not aware of non-integer multiples. Actually, 27 out of 33 adders on the interviews said that '*there is no multiple relation between 5 and 3*'. Non-awareness of a non-integer multiple *as* a multiple was the main reason that most of the Taiwan adders switched their multiplicative algorithms to the incorrect-addition strategy.

ii) The use of fractions/decimals

The six level three adders could use fractions/

decimals to amplify their multiplicative algorithms on the easy items. Out of the other 27 adders, eight used fractions, as Table II shows.

Table 11. Extraction of fractions used N=27

Adder	Algorithms (r: correct response) (w: incorrect response)	Item
Y	r: $2\div 8=\frac{1}{4}$, $\frac{1}{4}\times 4=1$	1(1)
	r: $\frac{15}{10}\times 12=18$	2a(2)
	r: $\frac{10}{15}\times 9=6$	2a(3)
	r: $15\div 9=\frac{5}{3}$, $25\div\frac{5}{3}=15$	2b(2)
	r: $\frac{25}{10}=\frac{5}{2}$, $10\div\frac{5}{2}=10\times\frac{2}{5}=4$	2b(3)
N	r: $8\div 6=\frac{4}{3}$, $2\div\frac{4}{3}=\frac{3}{2}$	1(2)
F	w: $8\div 6=\frac{4}{3}$, $2\times\frac{4}{3}^{*}=\frac{2}{3}$	1(2)
	r: $9\div 6=\frac{3}{2}$, $4\times\frac{3}{2}=6$	2a(3)
K	r: $2\times\frac{1}{2}=1$	1(1)
	w: $2\times\frac{1}{3}=\frac{2}{3}$	1(2)
Q	w: $\frac{15}{9}\times 25=41\frac{2}{3}$	2b(2)
	w: $\frac{25}{10}=\frac{5}{2}$, $\frac{5}{2}\times 10=25$	2b(3)
G	w: $15\div 9=1\frac{2}{3}$, $1\frac{2}{3}\times 5=8\frac{1}{3}$	2a(3)
	w: $15\div 9=\frac{15}{9}$	2b(2)
R	w: $15\div 9^{*}=\frac{9}{15}=\frac{3}{5}$, $25\times\frac{3}{5}=5$	2b(2)
J	w: $2\times 1^{*}=\frac{1}{2}$	1(2)

• indicates wrong computation.
Letters A,B,C,...Z, are used to name adders.

It seems that only one out of these 27 adders could use fractions to amplify her multiplicative algorithms. Many of these adders could not cope with fractions. For example, on the recipe question 1(1) with ratio 8:4, 19 adders could cope with it by using a multiplicative strategy. On item 1(2) with ratio 8:6, where a fraction is demanded when the multiplicative strategy is used, only 5 out of these 19 used the correct multiplicative strategy consistently. Out of the other 14, 10 switched their strategies (6 to 'building up', 2 to 'bigger so adding', 2 used inappropriate data), so they were able to avoid using fractions, 3 showed difficulties with using fractions, and one used decimals accompanied with an inappropriate procedure. Manipulating fractions is not a ready skill for these adders.

In the interviews, adders were asked to do some fractions' computation items and to solve a word problem (3 cakes shared by 5 people). Out of 27 adders, 20 could do addition/subtraction of fractions, such as $\frac{1}{2}\pm\frac{1}{3}$; 21 could do multiplication of fractions, such as $\frac{1}{2}\times\frac{3}{4}$; $\frac{1}{4}\times\frac{2}{5}$; 16 used *decimals* to present the answer of division of fractions; such as 5 ÷3, 3 ÷5; and 11 could solve the word problem. Some errors which they made, such as

$$\frac{1}{2}\times\frac{3}{4}=\frac{2}{4}\times\frac{3}{4}=\frac{6}{4}=\frac{3}{2}$$

$$40\div 10\frac{1}{2}=40\div\frac{21}{2}=\frac{1}{40}\times\frac{21}{2}$$

did reflect their learning style, which was learning by rote.

If we take the point of view that understanding fractions means one can apply this understanding appropriately in any context, then most of the Taiwan adders have a poor understanding of fractions, though they can do computation of fractions by taught algorithms.

For the CSMS adders, Hart (1984, p.23) says, "indeed, there is no evidence of an 'adder' using multiplication of fractions and the standard algorithm for such." The CSMS adders rarely used fractions, whereas some (14 out of 33) Taiwan adders did use it. However, both the CSMS and Taiwan adders generally have a poor understanding of fractions.

Two adders consistently used *decimals* to present the results of their multiplicative algorithms. One adder was able to apply the unitary method and gave the unit as a decimal on the recipe question. One adder used decimals on three items, but all three were incorrect responses. There are 12 other adders who also used decimals once or twice, but only when the divisor was 2 or 10. At most, three adders were able to use decimals from their equipment of skills when they attempted to solve ratio problems. On the other hand, these adders were able to use decimals on pure computation items, as we described above. It seems that many adders thought that, given that the ratio test items were all expressed in integer form, they should be solved using only the integer domain.

We now turn to two aspects which were not covered in Hart's (1981, 1984) research but which were investigated in these interviews. These were included to provide a fuller understanding of adders' characteristics.

iii) Awareness of 'within' and 'between' ratios

The multiplier and unitary methods have also been discussed by other researchers (e.g., Noelting, 1980a, b; Karplus *et al.*, 1983b; Freudenthal, 1983) under the labels '*between* ratio' and '*within* ratio' strategies.

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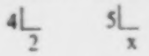
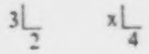
Regarding the geometric enlargement questions, the ***between ratio method*** is used by the adder who concentrates on the ratio of two corresponding portions *between* two figures; the ***within ratio method*** is used by the adder who concentrates on the ratio of two portions *within* a figure.

Most of the Taiwan adders were aware of one kind of ratio but might not have been aware of both kind of ratios. For example, on item 3(1), where both between and within ratios were 2:1, 16 (out of 27) used the between ratio method and 6 used the within ratio method successfully. Out of the 16, due to the similarity of the between ratios of items 3(1) and (2), 14 used the same method successfully on item 3(2), and two were confused by the disconnected diagram in item 3(2). Out of these 6, due to the complexity of the within ratio 3:2 on item 3(2), three switched to the incorrect addition strategy and the other three just repeated the similar algorithm (6 : 2) that they used on item 3(1) (8 : 2) to solve item 3(2). None of the adders showed an ability to switch from within ratio to between ratio.

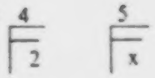
The following excerpt in the interviews shows that adder Chen, who was at understanding level three, was unable to switch from between-ratio to within-ratio.

I: 

Chen: "4 and 5 has no multiple relation. $x = 2 + 1$".

I: 

Chen: "4 is 2 times 2, $x = 3 \times 2$".

I: 

Chen: "$x = 2 + 1$".

iv) Distinguishing ratio from non-ratio contexts

Some Taiwan adders identified the type of question, additive or multiplicative, by checking some key words in the problem sentences. Some, when they used the naive methods, 'bigger so adding/multiplying' and 'smaller so subtracting/dividing', chose their operations in terms of how comfortable they felt about the numbers to be operated on.

Educators, generally, expect students to solve problems according to the following process:

(i) identification of the type of question,

(ii) application of 'the' method (Hart, 1984).

Was this the case for the Taiwan adders? To investigate this point, a non-ratio question, the truck question, was asked during the interviews. This was the truck question:

"Given the total weight, 5 tons, of a truck with 3 tons of goods, find the total weight of this truck with 6 tons of goods."

The surface structure of the truck question, given three values to find the missing value, is similar to the missing-value type of proportional problem.

The five adders who consistently used additive algorithms in the ratio test were not intending to use the multiplicative algorithm, so they naturally had no difficulty in identifying the type of the truck question.

Out of the six level three adders in the interviews, one identified it properly, four used the multiplier method on it, and one, Shen, extracted the data from the context and used the incorrect-addition strategy on it.

Shen: "$\frac{3}{6}\,\frac{5}{x}$, both have a difference of 2."

I: What does two mean?

Shen: The difference between 5 and 3.

Even when the interviewer asked him again, Shen was unable to explain that two means the weight of the truck.

Out of the other 22 adders, 11 solved the truck question correctly, 10 used the multiplier method on it and one used the incorrect-addition strategy on it.

The adders (14 out of 33) who used the multiplier method on the truck question were not processing as educators expected and tended to solve the problem by repeating methods used on the test paper. This is an example of the so-called 'capture efect' (Skemp, 1979).

4. Summary of Findings

Almost all the Taiwan adders used taught multiplicative algorthms on the easy items of the ratio test. Unlike the English adders who were only working in the addition system, the Taiwan adders were also working in the multiplication system, especially on easy items. From this point of view, Taiwan adders are not really 'adders', in the true sense of that word.

In terms of the above findings, some characteristics of the Taiwan adders could be summarized in the following table. To make a comparison, we have also listed the characteristics of the CSMS adders in Table 12. Generally speaking, the Taiwan adders behaved very differently from the CSMS adders. Evidence from other Taiwan studies (Lin, 1988) suggests that the main reasons for these differences lie with the very different teaching approaches to which the two sets of students are exposed. In Taiwan the teaching emphasis in on conventional algorithms, while in the UK teachers encourage students to make use of whatever method suits them best, so students develop what Booth (1981) called 'child-methods', "which are based on counting, adding-on or building-up approaches, and by which children attempt to solve mathematical problems within a human-sense framework."

Table 12. Characteristics of 'adders'

Adder Aspect	The Taiwan adders	The CSMS adders
Multiplicative methods	• use them predominantly on easy items	• never use them
On easy items with ratios 1:2, 1:3 e.g., item 1(1), 2a(1), 3(1)	• can cope with them by using algorithmic methods e.g., 'multiplying 2(3)', 'dividing 2', repeated addition	• can cope with them by using addition-based methods, e.g., 'halving', 'doubling' 'building-up'
On harder items e.g., item 2b	• think of multiplying, however their multiplicative methods were not secure	• use addition-based methods with difficulties
On the addition-type questions	• switch to incorrect-addition strategy because of, e.g., non-awareness of non-integer multiple, obstacles of the geometric settings	• view them as a natural addition-type questions (to make enlargement means to add)
Fractions	• can do operations of fractions by taught algorithms (learning by rote) • manipulating them is not a ready skill • poor understanding	• avoid using multiplication of fractions and the taught algorithm • poor understanding
Process of solving problems	• use multiplicative methods consistently by some of them • inappropriate, divorced from understanding • "Capture effect"	• use inconsistent methods - ask themselves "what would be most useful here?"
Non-integer multiple	• non-awareness	(no evidence)
Within and Between ratios	• aware of one kind of ratio only	(no evidence)
Distinguishing contexts	• poor	(no evidence)

IV. Implications

The learning difficulties we have found in this study may not only apply to adders in Taiwan but may also apply to children in other junior high school mathematics classrooms. In terms of the findings in this study, some suggestions should, therefore, be made for developing diagmostic teaching modules which we hope would be of benefit to all students.

1. Taiwan adders were able to use multiplier and unitary methods on easy ratio problems. Therefore, instruction which is based on the 'for-every' strategy (Case, 1978; Gold, 1978) could link to their abilities and, therefore, be of benefit to them.
2. Activities which lead to 'cognitive conflict', as Hart's (1984) module emphasized, have proven to be very motivating in bringing about cognitive and conceptual change (Kuo *et al.*, 1986). Apart from these activities, it would be better for every lesson to include some non-ratio questions so that adders have a chance to distinguish between a constant ratio relationship and a constant difference relationship. This activity has also been suggested by Karplus *et al.* (1983b). In this way, they can gradually develop an appropriate process for solving problems, i.e., based on understanding.
3. In terms of poor understanding of fractions, the concept of a fraction and its operations should be emphasized. Using a calculator to grasp the meaning of $\frac{7}{3}$ and $\frac{3}{7}$, as Hart's (1984) module showed, roven to be very effective for Taiwan

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adders (Kuo *et al.*, 1986).

4. A formal method of finding multiples, i.e., find x in a.x=b, should be learned and the awareness of a non-integer multiple should be developed.
5. After one or two lessons of learning ratios, students might develop some understanding of ratios. Then, both within and between ratios should be emphasized, so that the flexibility of choosing the more economic kind of ratio to match the context can be developed. Within the LOGO environment, Hoyles and Noss (1988) asked students to draw an L-shape diagram first and then to write a general program with one parameter, say the base, for all similar L-shape diagrams. In such a way, students had to express the upright as a function of the base, and their awareness of within ratio was expected to develop.

Furthermore, the mathematical features of the four understanding levels which were found in a previous study (Lin *et al.*, 1985) should be taken into account when arranging the sequence of the materials.

Finally, the non-rectilinear K question, i.e., ratio of curves, proved to be the best instrument for identification of adders in Taiwan. However, based on the interviews with five 16+ year old students who could cope with the K question, we found that students' understanding of ratio of curves required ideas of 'partition of curves', 'locally linear' and 'limit of ratios'. At this stage, the adders might not be ready to learn all these concepts. Thus, it is recommended that ratio of curves not be included in the actual teaching module.

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References

Booth, L.R. (1981). Child-methods in secondary mathematics. *Educational Studies in Mathematics*, *12*, 29-41.

Case, R. (1978). A developmentally based theory and technology of instruction. *Review of Educational Research*, 48.

Chick, H.L., Watson, J.M. and Collis, K.F. (1987). *Using the SOLO Taxonomy for error analysis in mathematics*. Paper presented at the Mathematics Education Research Group of Australia Conference, Townsville.

Freudenthal, H. (1983). *Didactical phenomenology of mathematical structures*. D.Reidel Publishing Company, Ch.6.

Gold, A.P. (1978). *Cumulative learning versus cognitive development*. Ph.D. thesis, University of California, Berkeley.

Hart, K.M. (1980a). *Secondary school children's understanding of ratio* and proportion. Ph.D. thesis, Chelsea College, University of London.

------ (1980b). *Secondary school children's understanding of mathematics*. A report of the Mathematics Component of the Concepts in Secondary Mathematics and Science (CSMS) programme, Chelsea College, University of London.

------ (1981). *Children's understanding of mathematics: 11-16*. John Murrat.

------ (1984). *Ratio: Children's strategies and errors*. Windsor: NFER-Nelson Publishing Company Ltd.

Hoyles, C. and Noss, R. (1988). The computer as a catalyst in children's proportion strategies. *Journal of Mathematical Behaviour*, in press.

Karplus, R., Karplus, E., Formisano, M. and Paulsen, A.C. (1975). *Proportional reasoning and control of variables in seven countries*. Advancing Education Through Science Programs, Report ID-65.

Karplus, R., Pulos, S. and Stage, E.K. (1983a), Proportional reasoning of early adolescents, in R. Lesh and M. Landau (eds.) *Acquisition of mathematics concepts and processes*. New York: Academic Press.

------ (1983b). 'Early adolescents' proportional reasoning on 'rate' problems. *Educational Studies in Mathematics*, *14*, 219-233.

Kuo, F.P., Lin, F.L. and Lin, K.H. (1986). *Diagnostic teaching: ratio*. A report of the Mathematics Understanding of Taiwan (MUT) students programme, Dept. of Mathematics, National Taiwan Normal University (in Chinese).

Lin, F.L., Kuo, F.P. and Lin, K.H. (1985). *Junior high school children's understanding of ratio and proportion*. A second year report of the Mathematics Understanding of Taiwan (MUT) students programme , Dept. of Mathematics, Taiwan Normal University (in Chinese).

Lin, F.L. (1988). Societal differences and their influences on children's mathematics understanding. *Educational Studies in Mathematics*, *19* ,471-497.

Lin, K.H., Lin, F.L. and Kuo, F.P. (1986). *Junior high school children's understanding of ratio-a longitudinal study*. A third year report of the Mathematics Understanding of Taiwan (MUT) students programme, Dept. of Mathematical Science, Chengchi University, Taipei, Taiwan (in Chinese).

McLeod, D.B. (1986). *New approaches to research on attitude*. Paper prepared for T. Romberg and M. Smith (eds.), *The monitoring of school mathematics*.

Noelting, G. (1980a). The development of proportional reasoning and the ratio concept, Part I - differentiation of stages. *Educational Studies in Mathematics*, *11*, 217-253.

------ (1980b). The development of proportional reasoning and the ratio concept, Part II - problem structure at successive stages, problem-solving strategies and the mechanism of adaptive restructuring. *Educational Studies in Mathematics*, *11*, 331-363.

Piaget, J. and Inhelder, B. (1958). *The growth of logical thinking from childhood to adolescence*. London: Routledge and Kegan Paul.

Ruply, W.H. (1981). *The effects of numerical characteristics on the difficulty of proportional problems*. Doctoral dissertation, University of California, Berkeley.

Skemp, R.R. (1979). *Intelligence, learning and action*. John Wiley & Sons, p.140.

Vergnaud, G.(1980). Didactics and acquisition of multiplicative

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structures in secondary schools, in W.F. Archenhold, R.H. Driver, A. Orton, and C. Wood-Robinson (eds.), *Cognitive development research in science and mathematics*. Leeds, England: University of Leeds.

------ (1983). Multiplicative structures, in R. Lesh and M. Landau (eds.) *Acquisition of mathematics concepts and processes*. New York: Academic Press.

比例推理時‘加者’的特徵

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摘 要

比例推理時的‘加者’，是指一致地使用不正確的加法策略，處理較難的比例問題的人。爲了調查這些‘加者’在處理一般比例問題時的解題策略，以及犯錯的理由，我們訪談三十三位台灣國中生中的‘加者’，對於較簡易的比例問題，這些台灣‘加者’的解題策略主要是用乘除運算，這跟英國的加者依賴加的策略很不一樣。爲了能較完整地描繪台灣‘加者’的特徵，訪談項目包括：非整數的倍數之察覺能力，分數與小數的應用能力，圖形內線段比與兩圖形間對應線段比的察覺能力，以及比例與非比例問題的辨別能力。我們發現台灣加者使用不正確加法策略的主要原因是，不承認非整數倍是一種倍數關係。

最後，將台灣加者與英國加者的特徵，列表比較。

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Development of CAG Model for Developing Instructional Materials for Teaching Physical Science Concepts for Grade 8 Students

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ABSTRACT

An instructional model based on a learning cycle including Correlation, Analysis, and Generalization (CAG) was developed and applied to design an instructional module for grade eight students in Taiwan, Republic of China. The CAG model was based on Piagetian theory and a concept model (Pella, 1975). The module developed for heat and temperature was administered to test its effects by comparing its use with the same unit in the New Physical Science Curriculum (NPSC).

The population was comprised of classes selected from four types of schools.

The treatments given were instructional materials, teacher training, pretest, and posttest.

Students who were in the experimental group received a copy the CAG module. Students who were in the control group used to NPSC (1988) material.

The major findings are presented as follows:

1. The CAG module tended to move science learning in an effective way. The experimental group performed significantly better than the control group on almost half the items in the posttest and 75 percent of the items in the follow-up test. The control group did not achieve significantly better results on any of the items of the posttest and follow-up test.
2. Academic ability and reasoning skills of students were related significantly to achievement. It is recommended that instructional materials be developed that are appropriate for each specific grade level.
3. Concrete written materials tended to have a positive impact on science achievement for eighth grade students.
4. Piagetian logical thinking was found to be a significant predictor for science achievement. Students performed well on both the concrete and transitional levels of the contents. Items on the formal leve! were difficult.
5. Several student misconceptions related to the topics were detected in the tests and interview analyses.

Key words: instruction, model, grade 8, learning cycle, physical science, science concept, concept development

I. Introduction

The Republic of China has developed and put into practice a new science curriculum for elementary and secondary schools. The new science curriculum has been used at elementary levels since 1978. It has also been used at secondary levels, beginning with seventh grade students who have completed the new curriculum at the elementary level.

The New Physical Science Curriculum (NPSC) is one of the new science curricula for the junior high level in the Republic of China. NPSC was designed to emphasize laboratory and other hands-on activities. The NPSC activities start with objective statements

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and follow with collecting data. They finish with using discussions related to the collected data. The NPSC looks like a Piagetian learning cycle (exploration, conceptual invention and expansion). It seems, however, that there is little emphasis on the expansion stage and little connection among activities. The tests of the NPSC indicate that many students have not been achieving important learning objectives of the NPSC program.

The present study was designed to provide empirical knowledge related to the design of instructional materials and activities to facilitate the learning of concepts and process skills in specific topics of science subject matter. An instructional model (a CAG model which is a learning cycle of Correlation, Analysis, and Generalization) which incorporated Piagetian theory and a concept model (Pella, 1975) was developed and applied to design an instructional module for grade eight students. The module developed for heat and temperature was administered to test its effects by comparing its use with the same topic of the unit in the New Physical Science Curriculum (NPSC).

The major problems of this study were to: (1) develop and analyze an instructional model for a science unit designed for grade eight students; (2) determine the module's impact on science achievement; and (3) identify what should be done to further improve the materials and instrction.

Piagetian theory proposes that a child's adaptation to his environment is accomplished in two ways; assimilation and accommodation. Assimilation involves making a response to what has been already acquired. Accommodation is a modification of a response. Whenever a child responds in terms of activities he already knows, he is said to be assimilating. On the other hand, when a change in behavior takes place by assimilating a new stimulus, this is called accommodation. Assimilation takes place in a new situation that is somewhat "related" to the preexisting knowledge which the learner has. Accommodation, on the other hand, takes place when a new situation is somewhat strange (Lefrancois, 1975).

An instructional model developed by the researcher and based on the Piagetian theory is shown in Figure 1. This model was related in developing the CAG model in this study.

A learning cycle (exploration, conceptual invention, and expansion) has been developed by Karplus (Renner *et al.*, 1983) for SCIS. A functioning model and a teaching model has been developed by Renner *et al.* (1983). Comparison of a functioning model and teaching model of a learning cycle is presented in Figure 2.

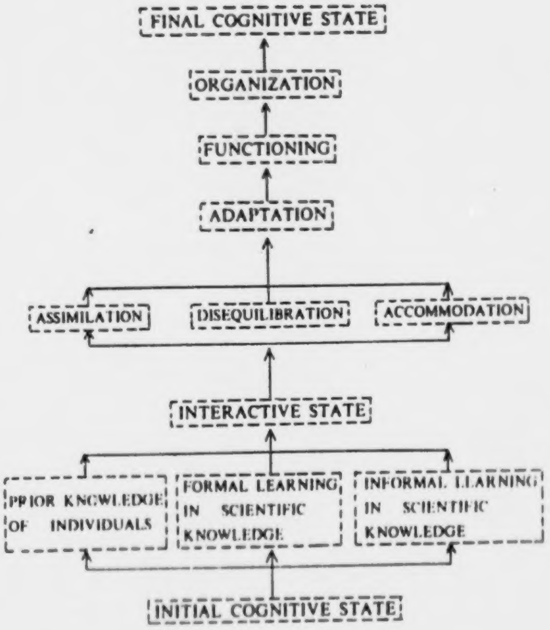

Figure 1. The Piagetian Instructional Model Developed by the Researcher

The tasks involved in the phase of exploration should result in assimilation of learning. The tasks provide students with time and opportunity to assimilate data about the concept that the teacher wants them to learn. But, since the data will be new to the students, their collection and interpretation give rise to many questions such as, "What's this?" , "How does this work?", "What does this finding mean?" and so on. Those questions are evidence that disequilibrium is present and that the students are asking for assistance in putting their thoughts in accord with the things they have just explored. In other words, they are ready for accommodation.

Functioning model		Teaching model
Assimilation	<----->	Exploration
Disequilibration & Accommodation	<---->	Conceptual invention
Organization	<---->	Expansion of ideas

Figure 2. Functioning Model Versus Teaching Model ··· Piagetian Learning Cycle (Renner *et al.*, 1983)

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Evidence of readiness can be used by the teacher to lead the students to consolidate their data and arrive at the concepts underlying the entire experience. The tasks involved in the phase of conceptual invention should lead to equilibrium of the learner's cognitive structure.

The tasks involved in the expansion of ideas should result in the reorganization of the learner's cognitive stucture (the learner should formulate a new system in his cognitive structure).

Pella (1975) has classified science concepts into three levels of sophistication: descriptive, comparative, and quantitative. He identified the descriptive as the lowest level and quantitative as the highest level. A descriptive concept identifies an object, event, or phenomenon as a member of a class of objects, events, or phenomena. Science uses concepts of this kind largely for description of observational findings for the formulation of initial, relatively imprecise, empirical laws. Comparative concepts make use of descriptive concepts but also make use of the idea of "degrees of "or "extent of", rather than merely "present or absent." Comparative concepts indicate how one object or event is related to another in terms of more, less, or the same. Quantitative concepts use a quantitative language in which there are symbols for functions that have numerical values which represent measures. Quantitative concepts serve to show how an object, function, or phenomenon relates to an accepted standard to which a numerical value has been assigned. Thus, the laws of nature are more precisely described.

II. The Development of Model and Materials

The Development of the CAG Model

Based on Piagetian theory, an effective instructional strategy is a learning cycle which moves from the exploration phase through the invention phase to the expansion phase. Pella's (1975) idea of a concept model emphasizes that learning should move from low levels to high levels in a three dimensional space which consists of the dimensions of sophistication, abstractness, and complexity. By combining both Piagetian theory and Pella's concept of concept ideas, materials can be developed to help a learner move from an undeveloped stage through the developing stage to the developed stage and from a low level developing stage to the developed stage and from a low level of concept understanding to a high level of concept understanding.

The CAG (Correlation, Analysis, and Generalization)model consists of five steps whichin clude one step of correlation and two cycles of analysis and generalization. The diagram in Figure 3. describes the CAG model. The first step is to correlate the learned concepts to form a new concept. For instance, the change of mass of a sample under discussion and its change in temperature can be correlated to the heat energy introduced or removed from a sample. By dealing with the correlations of prior concepts, a new concept can be developed as the schema of a learner. The second and the third steps are the first cycle of analysis and generalization. In the second step the method of analysis or differentiation is used to move the concepts from the descriptive type through the comparative type to the quantitative type. In this step a learner's schemata on the concepts can be developed in multiple facets. The third step is the process of integration. The concepts acquired from the second step are integrated or generalized, based on their commonality. A simple generalization of the concept should be drawn.

Concrete laboratory tasks are appropriately used in the learning cycle. The schemata can be developed more effectively if the activities are based on the learner's concrete experiences. The first three parts of the CAG learning cycle are very similar to the exploration and invention phases of the Piagetian learning cycle.

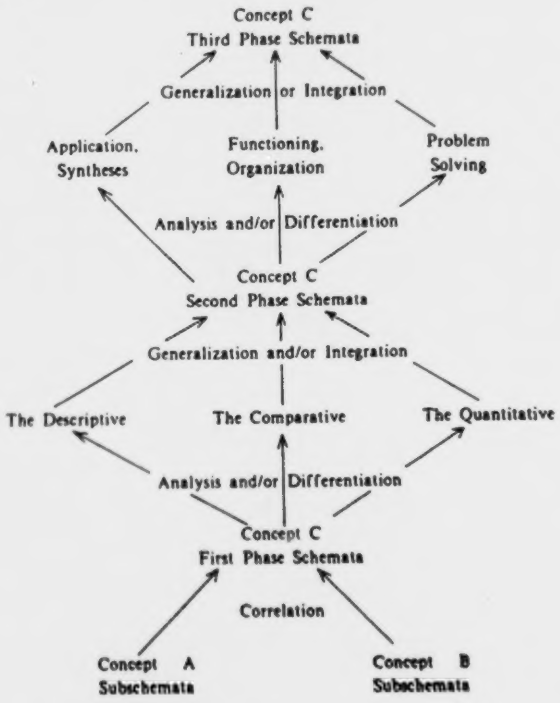

Figure 3. The CAG Model

The fourth and fifth steps in the CAG learning cycle are the second cycle of analysis and generalization. In the fourth step, more complicated natural phenomena are related to the concept and are analyzed in relation to a theme, a big idea, or a problem. In this step the learner's schemata related to the concepts can be developed more than before so that it can deal with more complicated natural phenomena. The fifth step is a higher order of generalization or integration. Combining the commonality among the themes, big ideas, or problems helps enable students to generalize the ideas.

In this part of the cycle, discussion and lecture are appropriately used. It is important to provide students with opportunities to organize their learning more effectively based on the organizers related to the concepts. This cycle tends to push the learner's schemata in a systematic and scientific way.

The Development of the CAG Module

Based on the content area of the New Physical Science Curriculum (NPSC, 1988), a unit on temperature, heat, heat transfer, and specific heat was developed based on the CAG model. Hands-on-activities and work sheets were developed for laboratory work to focus student attention on the tasks.

The CAG module was developed in eight parts. Most of the contents were selected from physical science curricula or text books (Burkman, *et al.*, 1981; Williams, *et al.*, 1979; Ewen, *et al.*, 1988; Brandwein, *et al.*, 1980). Part of the contents were developed by the researcher. The eight parts of the CAG module in order are as follows:

1. Building a heat measure.
2. Temperature.
3. Heat.
4. Heat transfer.
5. Specific heat.
6. Method of mixtures.
7. Measurement of specific heat of an unknown metal.
8. Reviewing the concepts for the module.

Part 1, 'Building a thermometer' is a concrete task for constructing a thermometer. According to the set of activities, the relationship between the change of properties of a substance and its change of temperature are correlated. It also helps students to develop their schemata on the concept of temperature as a descriptive concept, a comparative concept, and a quantitative concept. The instructor plays a major role in leading discussion related to data to develop the simple generalization of temperature for the learners.

The second cycle of analysis and generalization is based on the sections titled as follows:

1. Relationship between the degree of temperature and the color of light given off.
2. Temperature is a measure of average kinetic energy.
3. What happens when an object takes in heat.
4. The exchange of temperature scales.

In the second part, the concept of temperature is developed in relation to more complicated natural phenomena. It provides more detail in the analysis of the natural phenomenta under the organizers, and the scientific concept of temperature is used in applications and problem solving. In this cycle instructional materials play the major role in helping students to generalize the ideas into scientific concepts.

Some exercises are given at the end of each section that can provide opportunities for learners to elaborate their schemata more effectively.

Part 3 develops the concepts of heat. The correlation of the amount of a substance and its temperature change to its thermal energy change is presented first.

The first cycle of the analysis and generalization is "Getting into hot water." Students are required to do the activities and answer the questions in the activities. The instructor is involved in the activities to assist and to conduct discussions based on the data collected by the students to develop a simple generalization of the concept of heat.

The second cycle of the analysis and generalization is focused on the sections titled as follows:

1. What is a calorie?
2. Thermal energy is made up of internal energies.
3. Heat and work.

The instructional materials play a major role in helping students to analyze in more detail the concept as it relates to natural phenomena and to generalize the concept of heat.

Part 4 is related to heat transfer. Conduction, convection, and radiation are correlated to the movement of heat. In the first cycle, each type of heat movement is analyzed and a simple generalization for heat transfer is analyzed and a simple generalization for heat transfer is developed. The second cycle of analysis and generalization is developed in the sections titled as follows:

1. Controlling the transfer of heat.
2. Solar heating.

More details of the natural phenomena are involved in the organizers. Students are aided in developing a generalization of the direction of heat transfer.

Parts five, six, and seven are related to the topic of specific heat. Part five deals with the correlation among the variables of specific heat. heat change, temperature change, and properties of substance. In order to become familiar with these relationships, several concrete examples are provided, and a table of thermal constants, such as specific heat, boiling points and melting points, is provided in the instructional material.

Part 6 provides examples of thermal contact, e.g., the method of mixture. This part relates to the first cycle of analysis and generalization of specific heat. The task moves the concept of specific heat from the descriptive type through the comparative type to the quantitative type. The problem-solving examples are designed to generalize the concept of specific heat.

Part 7 is related to the second cycle of analysis and generalization of the concept of specific heat. The measurement of specific heat for an unknown metal is involved in the activities. Several questions must be answered through investigations. The learner should develop an ability to generalize his learning more effectively.

Part 8 is the summary of a important concepts for this module.

III. Methods and Procedures

Population

The population was comprised of eighth grade classes in four types of schools that were among the five major types of schools in Taiwan, Republic of China. The four types of schools from which schools were selected were:

(1) selective schools in cities;
(2) urban schools;
(3) suburban schools; and
(4) town and country schools.

Schools were not selected from rural areas.

Half of the classes in each school were randomly asigned to the experimental group, and the other half of the classes were assigned randomly to the control group. The six teachers of experimental classes were involved in the experimental group and the six teachers of control classes were involved in the control group. The number of students in the experimental group was 277, and the number of students in the control group was 260.

Instruments

The pretest and the posttest developed by the investigator were the instruments used in this study.

The pretest had three parts: (1) prior knowledge; (2) mathematical knowledge; (3) Piagetian tasks. Prior knowledge assessed consisted of major concepts of temperature and heat which the students should have learned before grade eight. Mathematical knowledge included number concepts, skills of equation solving, and graphic skills that were required to learn the unit. The Piagetian tasks consisted of proportional reasoning, combinatorial reasoning, and propositional reasoning items that related to the reasoning skills needed to learn the materials presented.

The overall average item difficulty of the prior knowledge test was .51. The average item difficulty of the prior knowledge test at both the concrete level and the transitional levels was .51. The average item difficulties calculated by content areas were .56, .54, .53 and .42, corresponding to temperature, heat, specific heat and heat transfer, respectively. The reliability (KR-20) of the prior knowledge test was .58 based on the sample of this study.

The pretest contained 12 mathematics skill items. The overall average item difficulty of the mathematics skills was .62. There were item difficulties of .82, .77 and .28 at the concrete level, transitional level and formal level, respectively. The reliability (KR-20) of the mathematics skills test was .71 based on the sample of this study.

There were eight Piagetian items in the pretest. The overall average item difficulty of the Piagetian tasks was .68. There were item difficulties of .99, .81 and .33 at the concrete level, the transitional level and the formal level, respectively. The reliability (KR-20) of the Piagetian tasks was .55 based on the sample of this study.

The reliability (KR-20) of the overall pretest was .74 based on the sample of this study.

There were 40 questions contained in the posttest. The items of the posttest and the follow-up test were the same. The items of prior knowledge in the pretest were included in the posttest and the follow-up test. The items developed were based on the content of NPSC and used in a pilot test.

The overall average item difficulty of the posttest was .58 based on the sample of this study. There were item difficulties of .74, .63, and .28 at the concrete level, the transitional level and the formal level, respectively. The reliability (KR-20) of the instrument in the pilot test was .79. The reliability of the final form was .88 for the instrument when used as a posttest, and .90 when used in the follow-up test.

Procedures

Students in the experimental group received a copy of the CAG module. Students in the control group used the NPSC (1988) material. NPSC is the current science curriculum in the Republic of China.

Teachers in the experimental group received four hours of training to become familiar with the major ideas of the CAG model and the teaching strategies for the module.

A pretest was given to the students of both groups two days before the instructional treatment. Both experimental and control groups received about two weeks and four days of instruction on the topics of temperature, heat, heat transfer, and specific heat. After the instruction, both groups took the posttest. Two weeks after the posttest, the experimental and control groups both took a follow-up test. Between the posttest and the follow-up test an interview was administered to 28 selected students from both groups (14 students from the experimental group and 14 students from the control group). Each student was interviewed for 40 to 60 minutes.

Data Collection

Data collected included the following: (1) the student's personal background variables, including Chinese and mathematics achievement, student's sex, parental occupation, and student scores on prior knowledge and Piagetian logical thinking; (2) the student's science scores on the posttest and follow-up test; (3) the teacher's emphases in teaching the concepts; and (4) the student's reasoning related to the content areas.

The main purposes of this study were to determine the impact of the CAG model and its teaching strategies for eighth grade students and the strong predictors for student science achievement. Student reasoning on the concepts related to these topics after instruction was also studied.

IV. Conclusions

Conclusion 1: The treatment group achieved significantly better results than the control group on the achievement posttest and follow-up test (heat and temperature).

ANCOVA was run to test the group effects for the posttest and the follow-up test. According to the results in regression analyses mathematics achievement, Chinese achievement, Piagetian logical thinking, and school type were used as covariates to run analyses for the the posttest and the follow-up test.

The results of ANCOVA for the posttest and the follow-up test, respectively, showed a significant difference between the groups (F=27.63; df=1, 529; and P=.000) on the posttest, favoring the experimental group. A significant difference between the groups (F=75.53; df=1, 529; and P=.000) on the follow-up test favored the experimental group.

The effect size of the observed mean scores on the posttest was .41 and favored the experimental group.

The effect size was .73 for the observed scores of the follow-up test and favored the experimental group.

The effect size calculated by the adjusted mean scores for the posttest was .28 and favored the experimental group.

The effect size calculated by the adjusted mean scores for the follow-up test was .52 and also favored the experimental group.

It was concluded that the treatment had a significantly positive impact on students' science achievement. The mean treatment effect size reported by Anderson *et al.* (1983) comparing the National Science Foundation Curricula with traditional curricula was .37. The study of Weinstein *et al.* (1982) reported a mean effect size of .31 with a standard deviation of .70 when innovative curricula for high school were compared with traditional curricula. The treatment effect sizes measured by the posttest and follow-up test in this study were .28 and .52, respectively. The effect sizes were very similar to Anderson's and Weinstein's findings. However, this study was designed to compare an instructional module with an innovative science curriculum used in the Republic of China.

Conclusion 2: The data indicated that the unique features of the module (heat and temperature) contributed to the student's success.

The specific impact of the module can be determined by analyzing item difficulty. The adjusted item difficulty was calculated by analysis of covariance. Mathematics achievement, Chinese achievement, prior knowledge of science, and Piagetian logical thinking were used as the covariates. The control group did not perform significantly better than the experimental group on any items of the posttest or the follow-up test. Fifteen items of the posttest (including 11 high-scored items and 4 low-scored items) and 30 items (including 24 high-scored items and 6 low-scored items) of the follow-up test were found to have significant difference between the groups and favored the experimental group.

The unique characteristics of the module were:

(1) An emphasis on Piagetian logical reasoning.

The module included concern for logical reasoning based on Piagetian stages (Concrete, Transitional, Formal) with an emphasis on concrete and transitional activities and learning requirements. This type of structure has been recommended by others (Albert, 1978; Lawson, 1985; Renner, 1979; Shayer *et al.*, 1979; Staver, 1984) and has been found to be successful. This study indicates that formal learning activities and evaluation items are not apt to be successful with this age group in Taiwan, R.O.C. This finding also is consistent with previous research and provides further support for this consideration in curriculum development and instruction.

The findings from analyses of the difficult items related to content categories of concepts tended to be consistent with the findings of several researchers (Engel, Clough, & Driver, 1985; Erickson, 1979; Shaver, 1979; Wiser, 1988). Analyses of this study and the other studies cited indicated: a. difficulties existed with regard to the concepts of heat and temperature, the application of thermal equilibrium, and concepts related to kinetic theory; and b. reasoning skills were apparently required for learning appropriate levels of concepts.

(2) An emphasis on concept learning.

The module also included concern for concept learning based on Pella's (1975) model with an emphasis on the sequence of teaching concepts beginning with descriptive concepts and progressing through comparative concepts to quantitative concepts. This type of sequence to generalize the concepts has been recommended by Pella *et al.* (1975). No studies related to the concepts in this study were found that used Pella's model. Voelker (1968) found that children who were expected to generalize concepts were equally as successful as children who were specifically guided in concept acquisition by the teacher. Specific instructional sequences to teach science concepts to elementary school children have been conducted by others (Helgeson, 1968) and been found to be successful. This study found that the experimental group performed significantly better than the control group on each type of concept domain (P=.000). The finding of this study was consistent with the above studies.

(3) An emphasis on analysis and generalization cycles.

The strategies of effective development of schemata have been proposed and recommended by others (Chi *et al.*, 1981; Rumelhart & Ortony, 1977).

The module included concern for analysis and generalization cycles designed to move student's schemata from low stage to high stage. These learning cycles were developed by the investigator based on Chi's ideas for development of schemata. No studies were found that used this approach for the concepts in this study. The results of this study showed that the experimental group performed significantly better than the control group on each type of concept domain (descriptive, comparative, and quantitative concepts), applications of the concepts, and problem solving. The findings of this study support Rumelhart's and Chi's findings.

Conclusion 3: How specifically could the CAG model be improved through modification of materials, instuction and inservice activities?

The CAG module had a positive impact on science achievement. Several findings related to improving the effectiveness of the module are as follows:

(1) Take into account the prior conceptions of students.

That prior knowledge affects students' comprehension of science achievement has been found by others (Anderson, *et al.*, 1977; Lee, 1987; Welch, 1985). The correlations among heat energy changes, the quantity and property of the material concerned, and the temperature change of the material were identified as the most important are as of prior knowledge affecting students' comprehension of this module. The ability to solve equations was identified as the most important mathematical skill for learning the module. Further rewriting of the module should emphasize the prior knowledge of students.

(2) Elaborate more in the transitional level.

About 70 percent of the eighth grade students were identified as being at the transitional level or below. Results showed that students performed well on the posttest and follow-up test at both the transitional and concrete levels. Instructional materials which include concern for Piagetian logical reasoning with an emphasis on concrete and transitional activities and learning requirements have been recommended by several researchers (Albert, 1978; Lawson, 1985; Renner, 1979; Shayer, *et al.*, 1981; Staver, 1981). A recent study by Rogan (1988) found that more concrete teaching strategies resulted in more effective concept learning on thermal phenomenon. Instruction could be lowered from the formal reasoning level to the transitional level by providing more concrete pictures, examples, concrete tasks, or models to deal with more theoretical conceptual schemes such as by:

a. providing more concrete examples for generalized ideas for constructing thermometers;
b. providing more bridging stages for the activity tasks to deal with thermal equilibrium for multivariables and for specific heat activity; and
c. providing a concrete model for teaching kinetic theory.

(3) Take into account student misconceptions.

Misconceptions related to heat and temperature have been identified by others (Erickson, 1979; Engel, Clough, *et al.*, 1985; Summers, 1980). Results of interviews on students' reasoning in this study were found to be very consistent with the above studies. The major misconceptions were identified as follows:

a. More heat means higher temperature.

b. A substance with a larger specific heat will increase in temperature faster than a substance with a small specific heat (assuming equal mass and equal amount of heat).

c. Heat is composed of invisible particles.

Clement (1984) Proposed using analogical reasoning to deal with "deep" misconceptions.

Rewriting of the module should consider this approach by:

a. providing opportunities in the instruction for discussion of alternative ideas;

b. providing analogical reasoning; and

c. bridging activities to overcome the misconceptions.

(4) Develop carefully the schemata for problem solving and teach strategies for problem solving.

Problem solving has been identified as being related to the abilities of analysis and synthesis (NAEP, 1977). The strategies of problem soiving have been identified and it has been proposed that these strategies can be taught (Chi, *et al.*, 1981; Reif, 1981).

The CAG model is concerned with learning cycles, with an emphasis on the processes of analysis and generalization to develop schemata. Results of this study showed that the experimental group performed significantly better than the control group on the problem solving items (P=.000) in both the posttest and follow-up test. It was concluded that the CAG learning cycles had a positive impact on problem solving. More precise strategies for problem solving related to the contents in the module should be emphasized in the rewriting of marerials.

V. Implications and Recommendations

The results of this study show that the experimental group performed significantly better than the control group on each type of concept domain (descriptive, comparative and quantitative concepts), applications of the concepts, and problem solving. In terms of Piagetian reasoning levels, the experimental group performed significantly better than the control group at each level (concrete, transitional, and formal). The findings indicated that the experimental group performed well at the concrete and transitional levels of contents. Based on the above results, several implications and recommendations can be made as follows:

(1) Early Development of General Academic Skills for General Achievement

Data Showed that both the experimental and control Students with better academic ability (mathematics ability, language ability and reasoning skills) achieved better results.

The educational system needs to focus more attention (time, materials and evaluation) on students at an early age to develop these abilities and skills. Students with lower academic ability levels were not able to gain as much from either the control or experimental treatments. The range of scores between top and bottom students should be reduced.

(2) Use of the CAG MODEL to Revise Current National Curricula

Experimental students outperformed control students on all items where significant differences were determined. This included about 33 percent of the items on the posttest and 75 percent of the items on the follow-up test.

These data indicate that the module and the related instruction were statistically more effective than the control for the total group of students. In addition, five of six experimental classes were more effective than the control classes. The sixth comparison classes had essentially no difference between them when scores were adjusted.

Based on these data, the national curriclum material for this topic would probably be more effective if modified to fit the CAG model and if the instruction was modified to fit the CAG model.

Since this model was consistently more effective for this topic, it probably would be more effective for other units with similar content. The model should be used to revise at least two other similar topics to determine possible effectiveness. If the model is effective for these two units, then the government should consider substantial revision of materials at the eighth grade level based on the CAG model.

The CAG model was effective for increasing achievement and reasoning skills for grade 8 students. Part of the success was due to the use of more concrete and transitional material and experiences. Students at lower grades need to improve achievement and reasoning skills to be able to achieve at higher levels in higher grades. Therefore, student achievement might be further improved by introducing modules bassed on the CAG model in earlier grades. Three units should be modified at the grade 6 level to determine how effective they are. If the modules work as expected, they would help students to understand and achieve more. In addition, the modules would help students develop more effective reasoning skills.

If the grade 6 intervention is effective, then the government should consider designing curriculum based on the conceptual learning and reasoning skill development ideas developed in this study. An articulated and sequential curriculum of several years duration would likely produce students with better rea-

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soning skills and better understanding of science concepts.

(3) Use of the CAG Model to Improve Learning for Able Students and Female Students

Experimental students who gained most, compared to control students, were able students and female students.

Students with better preparation were able to easily grasp the ideas in the module and scored very high on the tests; two classes of able students did particularly well. These scores support the need for better science instruction at lower grades to help students develop better reasoning skills and understanding. They also support the use of the CAG model for materials at this grade level to challenge and help our more able students to achieve.

Since experimental female students outperformed control female students, the module design shows promise for providing an approach to help female students achieve better in science and to have a more positive attitude toward science. Use of additional modules will confirm or refute this finding. If this finding is confirmed, then the approach should be applied to more materials to provide more equal learning opportunities for female students.

This finding related to female students has international significance. In most countries, females do not do as well as males in science and have lower interest levels with regard to science. Since achievement often is related to interests and attitudes, increasing achievement may help improve female attitudes toward science. Use of a sequence of CAG modules in at least one other Eastern country and in one Western country would provide data to determine whether the achievement results might be generalizable.

(4) Reducing Student Misconceptions Related to Science

All students come to school with misconceptions about science concepts. This study adds to the developing literature of research related to misconceptions in physics.

While more research needs to be done to find more misconceptions, curricula should be developed that correct misconceptions. This study provides a model for improving learning by testing a module, determining misconceptions, revising the module, and then testing again.

The module used in this study should be revised based on misconceptions identified, tested with students and analyzed to determine if the revised module is more effective.

In addition, modules used earlier in the curriculum that relate to this topic should be analyzed to determine how they present the concepts; some of these units or modules should probably also be revised.

The development and testing of additional modules should follow a similar pattern to improve both the modules being tested and the curriculum of earlier grades.

References

Albert, E. (1978). Development of the concept of heat in children. *Science Education, 62* (3), 389-399.

Anderson, R.C., Reynolds, R.E., Schallert, D.L., & Goetz, E.T. (1977). Frameworks for comprehending discourse. *American Educational Research Journal. 14* (4), 367-381.

Anderson, R.D., Kahl, S.R., Glass, G.V., & Smith, M.L. (1983). Science education: A meta-analysis of major questions. *Journal of Research in Science Teaching. 20* (5), 379-385.

Brandwein, P.F., Yasso, W.E., & Brovey, D.J. (1980). *Energy: A physical science: Concept in science*. Curie Edition. Harcourt Brace Jovanovich Inc.

Burkman, E., Darrow, S.P., Redfield, D.D., & Snyder, W.R. (1981). *The natural world/1*. Silver Burdett Company, Morristown, New Jersey.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categoriation and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121-152.

Clement, J., & Brown, D. (1984). Using analogical reasoning to deal with "Deep" misconceptions in physics. *The Paper Funded in Part by FIPSE Grant* No. 6008302557.

Engel Clough, E., & Driver, R. (1985). Secondary students' conceptions of the conduction of heat; Bringing together scientific and personal views. *Physical Education*, 20.

Erickson, G.L. (1979). Children's conceptions of heat and temperature. *Science Education, 63* (2), 221-230.

Ewen, D., Nelson, R. J., & Schurter, N. (1988). *Physics for career education*. Third Edition. Prentice Hall Inc.

Helgeson, S.L. (1968). *The relationship between concepts of force attained and maturity*. Technical Report No. 43. Madison: The University of Wisconsin, Wisconsin Researb and Development Center for Cognitive Learning. ED 020 910.

Lawson, A.E. (1985). A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching*, 22 (7), 569-617.

Lefrancois, G.R. (1975). *Psychology for teaching: A bear always usually faces the front*. Second edition. Wadsworth Publishing Company, Inc., Belment, California.

Lee, T.Y. (1987). *The relationship of achievement instruction, and family background to elementary school science achievement in the Republic of China*. Dissertation of the Ohio State University.

NAEP, (1977), National Assessment of Education Progress. Science Technical Report, U.S.A.

NPSC, (1988), The New Physical Science Curriculum revised in 1988. National Editorial Center, Taiwan, ROC.

Pella, M.O. (1975). *Concept of concept*. University of Wisconsin, Madison.

Reif, F. (1981). Teaching problem solving--A scientific approach. *The Physics Teacher*, 310-316.

BEST COPY AVAILABLE

Renner, J.W. (1979). The relationships between intellectual development and written responses to science questions. *Journal of Research in Science Teaching, 16* (4), 279-299.

Renner, J.W., Abraham, M.R., & Birnie, H.H. (1983). *Sequencing language and activities in teaching high school physics: A report to the National Science Foundation.* Grant Number: SED-8015814.

Rogan, J.M. (1988). Development of a conceptual framework of heat. *Science Education, 72* (1), 103-113.

Rumelhart, D.E., & Ortony, A. (1977). The representation of knowledge in memory. In: R.C. Anderson, R.J. Spiro, & W. J. Montagne (eds.) *School and the acquisition of knowledge,* Hillsdale, NJ, Erlbaim.

Shayer, M. (1979). Has Piaget's construct of formal operations thinking any utility? *British Journal of Educational Psychology, 49,* 265-276.

Shayer, M., & H. Wylan (1981). The development of the concept of heat and temperature in 10-13 years old. *Journal of Research in Science Teaching,* 419-434.

Staver, J.R. (1984). Research on formal reasoning patterns in science education; Some message for the science teachers. *School Science and Mathematics,* Nov. 573-589.

Summers M.K. (1983). Teaching heat; Analysis of misconceptions. School Science Curriculum Review, 670-676.

Voelker, A. M. (1968). *The relative effectiveness of two methods of instruction in teaching the classificational concepts of physical and chemical to elementary school children.* Technical Report no. 39. Madison: the University of Wisconsin, Wisconsin Research and Development Center for Cognitive Learning, Ed 020 908.

Weinstein, T., Boulanger, F.D., & Walberg, H.J. (1982). Science curriculum effects in high school; A quantitative synthesis. *Journal of Research in Science Teaching, 19* (6), 511-522.

Welch, W.W. (1985). Research in science education: Review and recommendations. *Science Education 69* (3), 421-448.

Williams, G.A., Barnes, R.A., Doerhoff R.B., & Bolen, M.C., (1979). *Physical science: Challenges to science,* Second edition. Webster Division, McGraw-Hill Book Company, New York.

Wiser, M., & Kipman, D. (1988). The differentiation of heat and temperature: An evaluation of the effect of microcomputer models on students' misconceptions. *Draft article of a paper presented at AERA meeting,* New Orleans, Louisiana.

發展CAG模式及其教材用以教授國中二年級學生之研究

徐順益

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摘要

本文發展出一以"相關(CORRELATION)"，"分析(ANALYSIS)"以及"通則化(GENERALIZATION)"的三段式教學模式(A CAG MODEL)，再應用這個模式發展出一單元的物理科教材（溫度與熱），並用以教授我國國中二年級的學生，本文的主要目的在於實驗這種教學模式以及其教材在物理科教學的效果。四種形態的國中（明星，都市，城鎮及鄉村）學生被選爲實驗教學的母群，現行的物理科教科書（民國77年修訂本）之相關內容的單元（溫度與熱）被用爲控制教材。

主要的發現有：

(1) 在學生學習成就上，CAG 的教材顯著的優於現行的教材。

(2) 學生的學科能力(Academic ability) 和思考技能(Reasoning skills) 被發現與學生的學習成就有很高的相關，對於某特定邏輯思考能力的學生，本文建議若能應用適合程度的教材，則可導致較有效率的學習。

(3) 皮亞傑(Piagetian logical thinking) 邏輯推理能力的層次爲影響學習成就的主要因素。

(4) 有效率的國二教材傾向於多用具體層次內容之教材。

(5) 有關溫度與熱的幾個主要錯誤概念(Misconceptions) 亦在本研究中被發現。

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Reliability and Validity of Instrument to Assess Chemistry Manipulative Techniques - Capillary Melting Point Determination

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ABSTRACT

The traditional indexes of item difficulty, item discriminating power, and the correlation coefficient are of little value in determining reliability and validity of criterion-referenced mastery measurement (CRMM). A procedure has been designed in This Study to revise and validate the CRMM constructed specifically for the capillary melting point determination technique (CMPDT), one of the chemistry manipulative techniques (CMT). The validation procedure includes a novel application of S-P chart analysis used for the first time. The method of validating the tool uses positive correlations (1) between the results of pre-test/post-test 1 and post-test 1/post-test 2, (2) between the results of check-list and paper-pencil test, (3) between task performance and test result, and (4) among the results of a rational set of assignments. A computer program in BASIC has been written in This Study to quickly obtain necessary information on IBM PC. Conclusions: 1. Content validity of the tool is satisfactory for assessing whether students can perform CMPDT of ordinary cases in a college introductory organic chemistry laboratory courses. 2. Item validity is clearly observed in downward shifts of each item's portion of the P-curve, showing sensitivity of learning gain during a representative rational set of activities. CPj values of all items are less than 0.20. In the plots of Pj vs. CPj, all items are in Quadrant A. These facts indicate that all items are of good quality. Item reliability is observed from a rightward shift of that portion of the S-curve showing consistency of learning gain of individuals. 3. Criterion-related validity of the instrument is observed from the P-curve as a whole shifting downward in the three S-P charts. D^* values are 0.2785 for post-test 1 and 0.1965 for post-test 2. Performance on the check-list is found to be highly related (90.9%) to performance on the paper-pencil test. Those students (86.4%) for both the concrete and the identity levels and 90.9% for the classificatory level) with high scores in the paper-pencil test indeed obtained the accurate melting points. 4. Construct-validity with respect to learning transfer is observed in the individal performance profile for (a) task performances and (b) test results in a rational set of activities. 5. Reliablity of the instrument is observed in (a) the rightward shift of the S-curve as a whole and (b)81.8% agreement in two equivalent halves of items in the test, both (a) and (b) showing consistency of learning gain. 6. The procedure designed in This Study involving S-P chart analysis (a non-parametric method) is satisfactory in validating assessment tools for classroom CRMM, as demonstrated by the application to CMPDT, a CMT.

Key words: reliability, validity, criterion-referenced mastery measurement, S-P chart analysis, chemistry manipulative technique, melting point determination, assessment, non-parametric method, performance test, item-response pattern

I. Introduction

Since criterion-referenced mastery measurements (CRMM) are designed to describe which learning tasks a student can and cannot perform, rather than to discriminate among students, the traditional indexes of item difficulty, item discriminating power, and the correlation coefficient are of little value in determining reliability and validity of an instrument. Fur-

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thermore, necessary data usually available are only from classes of about 20-50 students. An item in CRMM, for example, might be answered correctly by all students (zero discriminating power) but still is an effective item. Since the items closely match all necessary learning outcomes, the results of the measurements simply indicate that here are outcomes that all studnts have mastered. Difficulty of an item in CRMM is determined by the learning task that the item is designed to measure. If the task is easy, the item should be easy. If the task is difficult, the item should be difficult. No attempt should be made to eliminate easy items or to alter item difficulty simply to obtain a spread of test scroes (Popham, 1978).

S-P chart analysis is a non-parametric method to analyze class performance data. It is preferable for classroom CRMM to the traditional test-score theory which relies on the normal distributi[illegible]surement (Sato, 1980, 1986, 1988). One of the characteristics of S-P chart analysis is that item-responses can be presented in a graphical mode. An anomalous item pattern may reflect an ambiguity or other deficiency in an item. An anomalous student pattern may indicate insufficient preparation with prerequisite skills or erratic study. These anomalous patterns are quantified by the Caution Index CPj for the j-th item and the Caution Index CSi for the i-th student. The degree to which the S- and the P-curves do not superimpose is expressed by D^* , the Disparity Coefficient. Passing Rate of item j (Pj) is the number of students who answered correctly (CA) divided by the total number of students. An increasing passing rate for an item after instructions shows sensitivity of learning gain. S-P charts are able to find out what the students have and have not learned.

The evaluation tool reported (Wang and Horng, 1989) for the capillary melting point determination technique (CMPDT), one of the chemistry manipulative techniques (CMT), is based on specific assessment criteria. Process concept analysis (Herron *et al.*, 1977) points out what, how, when, and why the learner must so perform the technique. Content analysis [structural task analysis (Gagnê 1987), hierarchical concept mapping (Novak and Gowin, 1984)] and evaluation analysis (Klausmeier and Sipple, 1980; Dumas-Carrê and Larcher, 1987) based on behavioral analysis are used to establish criteria which have led to construction of an evaluation tool to measure the learning levels attained . CMPDT is a multiple task. It cannot be measured by one assignment. It must be measured by a representative rational set of new assignments. CRMM for CMPDT must measure not only the accuracy of the performance but also the appropriateness of the performance, i.e., whether the performance is the correct response to the particular inputs (cues). In college introductory organic chemistry laboratory courses, students are expected to reach the classificatory level, so that later on they will be able to perform the technique in ordinary cases without difficulty. Task Performance Measure (TPM) involves actual performance (doing) by a learner. The task evaluation is based on the product and the process. A product is an output of a task which is observable. A process is also an output of a task which is observable but transient. The ideal tool has perfect predictive validity; without exception, those who pass can perform the job task well and those who fail can not. That is, performance in the test should be highly related to performance in the task. An effective evaluation item will be the one answered correctly by a larger number of students after instruction than before. Evidence of its sensitivity to learning gain is needed to evaluate its validity. Reliability of the tool can be observed from consistency in gain of learning within individuals in a rational set of experiments. The consistency of score gains in two equivalent halves of items in the test also provides a good estimate of reliability. A two-dimensional table of specification is constructed to structure the assessment tool in the check-list and paper-pencil test forms. One dimension of the table is the skill category, and the other is the behavior category. With these specifications, performance objectives are written so as to match the two categories, and evaluation items for the check-list and paper-pencil test are developed on the basis of these performance objectives.

The purpose of This Study is to design a procedure to revise and validate CRMM for CMPDT, one of CMT, in which is included a novel application for the first time of the S-P chart analysis and the relevant index variables. A computer program in BASIC for IBM PC has been written in This Study, which can quickly and effectively give necessary information for the analysis.

II. Methods

Sample: The samples for This Study include 22 freshmen and 22 sophomores in the Departmnet of Chemistry of National Taiwan Normal University.

Instrument: The CRMM of CMPDT was contructed on the basis of the specific assessment criteria which arise from analysis mentioned in Introduction. (1) Evaluation assignments are shown in Section 4, Part III. (2) Paper-pencil tests take the form of multiple-choice items; test items measure the student's attainment of the CMPDT at the specific learning level;

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each item is specifically for a part skill. Paper-pencil tests are administered in three phases. The pre-test was conducted before the first assignment to find out what the learner already knew. Post-test 1 was given after the first assignment. Post-test 2 was carried out right after a rational set of activities. (3) The check-list contains the key steps (such as uniformly packing the capillary tube) that an individual student must be observed for by the teacher and tape-recorded (for later reference) during the evaluation activities. (4) Clinical interviews were conducted by a teacher on those students who showed anomalous student pattterns in S-P chart analysis to find out what their learning difficulties were.

A procedure (Fig. 1) has been devised in This Study to revise and validate CRMM for CMPDT in which is included the S-P chart analysis using a specially designed computer program. CRMM for CMPDT is validated by positive correlations (1) between the results of pre-test/post-test 1 and post-test 1/post-test 2, (2) between the results of the check-list and paper-pencil test, (3) between the task performance predicted from the test results and the task performance actually attained, and (4) among the results of a rational set of assignments. The validation of the instrument is subdivided into 1. content validity, 2. item analysis, 3. criterion-related validity, and 4. construct validity, as discussed in Part III.

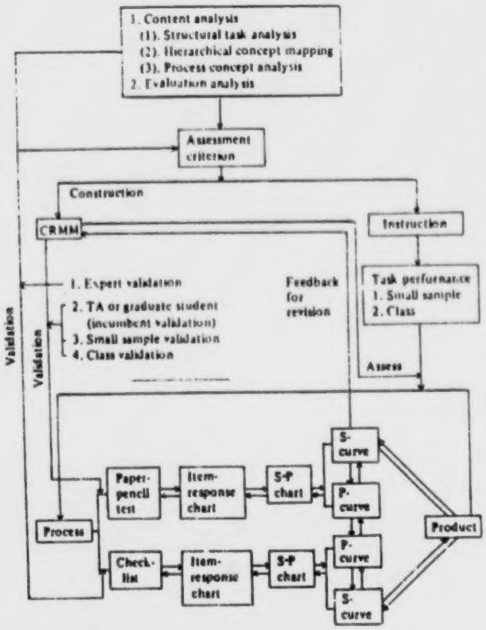
1. Content analysis
(1). Structural task analysis
(2). Hierarchical concept mapping
(3). Process concept analysis
2. Evaluation analysis
Assessment criterion
Construction
CRMM
Instruction
1. Expert validation
2. TA or graduate student (incumbent validation)
3. Small sample validation
4. Class validation
Feedback for revision
Task performance
1. Small sample
2. Class
Validation
Validation
Assess
Paper-pencil test
Item-response chart
S-P chart
S-curve
P-curve
Process
Product
Check-list
Item-response chart
S-P chart
P-curve
S-curve

Fig. 1. Flow chart of validation process.

III. Results and Discussion

1. Content Validity

Content validity requires both item validity and sampling validity (Thorndike and Hagen, 1969; Gay, 1980). CMPDT is a multiple task which must use a rational set of new representative assignments. Content validity was determined by a thorough inspection of the content and skill domains by three chemistry professors, one science educator, and three teaching assistants, The expert judgment was based on whether every kind of behavior listed in the two-dimensional table of specification had been included in the test. The content and learning outcomes included in the test were typically based on the leading textbooks (Roberts *et al.*, 1974, 1985; Cheronis and Entrikin, 1963; Williamson, 1987; Fieser and Williamson, 1987; etc.). The melting point is one of the physical constants. A pure solid usually melts reproducibly over a narrow range (0.5℃to 1℃). Contaminants usually lower the melting point and extend the melting point range. The simple melting point determination was done with an apparatus consisting of a capillary tube to hold the sample (less than 1 mg), a thermometer, and a heating bath. CMPDT has three critical attributes: (1) the solid is uniformly packed in a capillary tube; (2) the bath with the capillary is heated slowly; (3) the temperature range is recorded, at the lower end of which the solid begins to liquefy and at the higher end of which the whole becomes clear liquid.

2. Item Analysis

Learning achievement and its evaluation are effected by three factors. (1) Student's previous experience, willingness to learn, and ability to learn. (2) The curriculum structure and the teaching method. (3) The validity and the reliability of the evaluation tool. The third is influenced by the other two. Therefore, an effective validation procedure is needed to ensure the third factor in the presence of influences from the other two. A validation procedure (Fig. 1) involving the S-P chart analysis combined with the check-list and clinical interviews was designed to overcome this difficulty. In this procedure repeated feedbacks and revisions finally produced a good evaluation tool with a high degree of validity and reliability, which is confirmed by the high degree of agreement between the test results and the task performance as discussed in 3-2-2 (below). Three teaching assistants served as incumbents.

2-1. Item validity

Item validity is observed from the downward shift of that item's portion of the P-curve in the S-P charts.

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Table 1. S-P chart of CMPDT, pre-test.

PROBLEM NUMBER D*= 0.5787

STUDENT No.	09	10	05	06	17	18	15	16	13	14	01	02	07	08	11	12	19	20	03	04	CA	%	CSi
218	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	14	70	0.00
414	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	12	60	0.19
76	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	12	60	0.19
18	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	12	60	0.19
254	1	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	1	1	0	0	12	60	0.47
156	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	12	60	0.51
272	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	10	50	0.00
399	1	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	10	50	0.19
138	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	0	0	0	0	10	50	0.19
290	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	10	50	0.19
236	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	10	50	0.30
192	1	1	0	0	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	10	50	0.38
58	1	1	1	1	0	0	1	1	0	0	0	0	1	1	1	1	0	0	0	0	10	50	0.50
334	1	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	1	1	0	0	10	50	0.57
450	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	8	40	0.00
316	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	8	40	0.08
241	1	1	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	8	40	0.21
174	1	1	0	0	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	8	40	0.21
352	1	1	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	8	40	0.29
11	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	8	40	0.50
441	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	8	40	0.63
479	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	6	30	0.10
CA	22	22	15	15	15	15	15	15	13	13	10	10	10	10	05	05	03	03	00	00			
Pj. %	100	100	68	68	68	68	68	68	59	59	45	45	45	45	22	22	13	13	00	00			
	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			
CPj	.00	.00	.40	.40	.54	.54	.22	.22	.61	.61	.37	.37	.50	.50	.77	.77	.93	.93	.00	.00			

Table 2. S-P chart of CMPDT, post-test 1.

PROBLEM NUMBER D*= 0.2785

STUDENT No.	09	10	17	18	13	14	15	16	05	06	07	08	01	02	11	12	19	20	03	04	CA	%	CSi
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
334	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
156	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
290	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
236	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	18	90	0.56
241	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
399	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
218	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
352	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
76	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16	80	0.00
414	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	16	80	0.24
174	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	16	80	0.24
138	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0	16	80	0.29
254	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	16	80	1.03
192	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	14	70	0.18
272	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0	0	14	70	0.37
316	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	12	60	0.00
441	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	0	0	0	0	12	60	0.23
450	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	0	0	12	60	0.23
479	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	8	40	0.60
CA	22	22	21	21	21	21	21	21	20	20	19	19	17	17	16	16	11	11	03	03			
Pj. %	100	100	95	95	95	95	95	95	90	90	86	86	77	77	72	72	50	50	13	13			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CPj	.00	.00	.00	.00	.53	.53	.53	.53	.18	.18	.40	.40	.10	.10	.47	.47	.63	.63	.21	.21			

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Table 3. S-P chart of CMPDT, post-test 2.

PROBLEM NUMBER D*= 0.1965

STUDENT No.	01	02	05	06	07	08	09	10	11	12	15	16	17	18	13	14	19	20	03	04	CA	%	CSi
76	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
334	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
218	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
236	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
156	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
316	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
352	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
241	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
192	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
399	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
254	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
414	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
540	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
174	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
138	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
290	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
272	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
479	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
441	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	16	80	0.92
CA	22	22	22	22	22	22	22	22	22	22	22	22	22	22	21	21	21	21	16	16			
Pj. %	100	100	100	100	100	100	100	100	100	100	100	100	100	100	95	95	95	95	72	72			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CPj	.00	.00	.00	.00	.00	.00	.00	.00	.00	00	.00	.00	.00	.00	.00	.00	.00	00	.20	.20			

Downward shift represents sensitivity and uniformity of learning gain, which are observed by comparing the results (S-P charts) of the paper-pencil tests: (a) post-test 1 (Table 2) vs. pre-test (Table 1) and (b) post-test 2 (Table 3) vs. post-test 1. Item validity is further supported by (c) the check-list and clinical interviews. Item validity can also be observed from three more pieces of evidence: (d) Pj for every item increasing from pre-test to post-test 1 to post-test 2 as in Pj for item 20, increasing from 13% to 50% to 95%, showing sensitivity of learning gain; and (e) CPj of post-test 2 for CMPDT being all less than 0.20, meaning all items are good (CPj <0.50) (Sato, 1980); (f) in the plot of Pj vs. CPj, all items being in Quadrant A, meaning good quality (Fig. 2) (Sato, 1980).

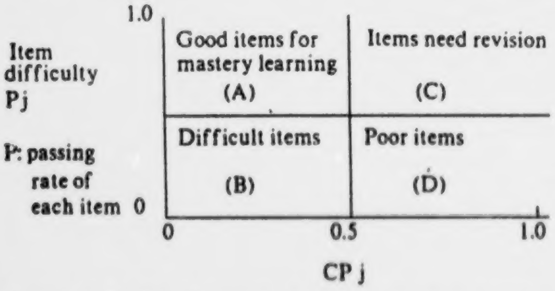

Fig. 2. Pj vs. CP j - Diagnosis of items for mastery learning.

2-2 Item reliability

Item reliability is observed from the rightward shift of that portion of the S-curve (Tables 1, 2, 3.), which shows consistency of learning gain and uniformity of individuals for each test item when administering (a), (b), and (c) mentioned above (2-1), and (g) two equivalent items.

3. Criterion-related Validity

The instrument is validated on the basis of the assessment criteria which points out what, how, why, and when the learner must do specifically for CMPDT. The validation procedure including the S-P chart analysis and clinical interviews are employed for the students with learning difficulties. The results are further confirmed by positive correlations in (1)-(4) in Methods.

3-1 Validation by S-P chart analysis

The S-P chart was used to analyze student response patterns in classroom tests. S-P chart analysis is a for-

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mative/diagnostic evaluation method. Each item of CRMM for CMPDT in the S-P chart is tied up to the criterion, i.e., the attainment target of the part skill. As attainment approaches the higher learning level, a higher degree of mastery of the part skill is observable. The P-curve as a whole has now been found to shift downward progressively from Tables 1 to 2 to 3, representing sensitivity of learning gain. The degree of actual gain compared to the degree of expected gain is used to confirm the criterion-related validity of the paper-pencil test in the edumetric dimension (Carver, 1974). Validity of CRMM of CMPDT is also observed in D^*. D^* decreases from 0.5787 (Table 1) to 0.2785 (Table 2) and finally to 0.1965 (Table 3), showing sensitivity of learning gain. These facts indicate that the instrument is of good guality, because D^* less than 0.5 is acceptable for multiple tasks (Sato, 1986).

3-2. Validation by expectancy table

The key elements in criterion-related validity are the degree of agreement between the two sets of measures: (1) the test scores, and (2) the criteria to be predicted. Expectancy tables can be used to show the relationship between a test score and an external criterion (Gronlund, 1982). In predicting success on CRMM, the categories are simply limited to two, mastery and nonmastery. The table shows, for each catgory on the predictor, how many students have demonstrated mastery or nonmastery on the external criterion (Gronlund, 1982). Degree of Agreement is 100 times (number of agreements in test score and external criterion)/(total number in the group).

3-2-1. Check-list and paper-pencil test

Performance on the check-list has been found to be highly related (90.9%) to performance on the paper-pencil test for post-test 2.

3-2-2. Process-product relationship

CRMM has high predictive validity, i.e., performance on the test should be highly related to performance of the task (Campbell, 1986). The task evaluation was based on the product and the process. For CMPDT, the observed melting point was the product of the task performance. Those students (86.4% for both the concrete and the identity levels and 90.9% for the classificatory level) with high scores in paper-pencil test indeed obtained the accurate melting points. Thus, the tool is confirmed to have high predictive validity.

4. Construct Validity

Construct validity is related to the extent to which the proposed learning level accounts for performance on the tasks of a rational set of activities having representative attributes. Validation with respect to learning transfer after training was made by observing the individual performance profile (Table 4), which shows pass/fail in the rational set of activities. In table 4, the first column (acetanilide) is the first assignment (typical case), the same task used in the instruction, which evaluated student's "recognition-repetition" ability. Students who failed in the first task (A) were required to repeat the same task

Table 4. Assignments and attainment level of individuals of CMPDT

Level	Concrete	Identity	Classificatory						Attainment level
Compound / St. no.	A	B	C	D	E	F	G	H	
192	+	+	-	-	+	+	-	-	identity
156	+	+	-	-	+	+	-	-	identity
011	-	+	+	+	+	+	+	+	classificatory
058	-	+	+	+	+	+	+	+	classificatory
479	+	+	+	+	+	+	+	+	classificatory
316	+	+	+	+	+	+	+	+	classificatory
450	+	+	+	+	+	+	+	+	classificatory
414	+	+	+	+	+	+	+	+	classificatory
399	+	+	+	+	+	+	+	+	classificatory
218	+	+	+	+	+	+	+	+	classificatory
241	+	+	+	+	+	+	+	+	classificatory
018	+	+	+	+	+	+	+	+	classificatory
352	+	+	+	+	+	+	+	+	classificatory
334	+	+	+	+	+	+	+	+	classificatory
290	+	+	+	+	+	+	+	+	classificatory
441	+	+	+	+	+	+	+	+	classificatory
174	+	+	+	+	+	+	+	+	classificatory
254	+	-	+	+	+	+	+	+	classificatory
138	+	-	+	+	+	+	+	+	classificatory
236	+	+	+	+	+	+	+	+	classificatory
076	+	+	+	+	+	+	+	+	classificatory
272	+	+	+	+	+	+	+	+	classificatory

+ mp is correctly determined.

- mp is incorrectly determined.

compound (mp, ℃)

A	acetanilide (114.2)	B	benzoic acid (122)
C	naphthalene (80-82)	D	p-dichlorobenzene (53.5)
E	p-toluic acid (180-182)	F	succinic acid (182.8)
G	anthracene (216.8)	H	phthalimide (233.5)

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after remedial instruction. The second column (benzoic acid) is the second assignment (comparable case), which evaluated student's "identification-reproduction" ability. Students who failed in the second task (B) were given a third task (C) selected from the rest of the rational set. Assignments other than A and B (naphthalene, p-dichlorobenzene, p-toluic acid, succinic acid, anthracene, and phthalimide) have representative attributes and should be able to evaluate a student's "generalization to all ordinary cases" ability. The + signs show successful performances. Students were considered to reach the classificatory level only if they successfully completed 80% or more of the assigned cases. The ability was confirmed by successfully performing an unknown task taken randomly from a large collection of cases of CMPDT. The last column records that 91% of the students reached the classificatory level; the rest remained at the identity level. These facts are further confirmed by learning gain shown in individual performance profiles constructed from the pre-test, post-test 1, and post-test 2 of the paper-pencil tests. Construct validity has now been further confirmed by the paper-pencil test results, which show the sensitivity and uniformity of learning gain of each student in going from the freshman to sophomore years.

5. Reliability of CRMM for CMPDT

The reliability of an evaluation tool is an indication of how well a test consistently measures what it is supposed to measure. The degree of reliability of the tool is based on the reliability of the items within a test device. Item reliability of the tests used in This Study has been established in 2-2.

5-1. Interrater reliability

The check-list contains the procedures that individual students must be observed for by the teacher. With four observers, interrater reliability has been ascertained by viewing videotapes and by round table discussions.

5-2. Reliability by S-P chart analysis

Reliability has been observed by the consistency of gain and the uniformity shown in the S-curve, which as a whole, shifts rightward progressively in going from Tables 1 to 2 to 3.

5-3. Comparing test performance on two equivalent halves of test items

The percentage of consistency (81.8%) has been computed by 100 times (number of agreements in both halves)/(total number in the group).

IV. Conclusion

Based on the findings and the discussion in the preceding sections, the following conclusions can be made.

1. Content validity of the instrument is satisfatory for assessing whether students can perform CMPDT of ordinary cases in college introductory organic chemistry laboratory courses.

2. Item validity is clearly observed in downward shifts of each item's portion of the P-curve, showing learning gain during a representative rational set of activities. CPj values of all items are less than 0.20. In the plots of Pj vs. CPj, all items are in Quadrant A. These facts indicate that all items are of good quality. Item reliability is observed from the rightward shift of that portion of the S-curve, showing consistency of learning gain of individuals.

3. Criterion-related validity of the instrument is observed from the P-curve as a whole shifting downward in the three S-P charts. D^* values are 0.2785 for post test 1 and 0.1965 for post test 2. Performance on the check-list is found to be highly related (90.9%) to performance on the paper-pencil test. Those students (86.4% for both the concrete and identity levels and 90.9% for the classificatory level) with high scores in the paper-pencil test indeed obtained accurate melting points.

4. Construct validity with respect to learning transfer is observed in the individual performance profiles for (a) task performance and (b) test results in a rational set of activities.

5. Reliability of the instrument is observed in (a) the rightward shift of the S-curve as a whole and (b) 81.8% agreement in two equivalent halves of items in a test, both (a) and (b) showing consistency of learning gain.

6. The procedure designed in This Study involving S-P chart analysis (a non-parametric method) is satisfactory in validating assessment tools for classroom CRMM, as demonstrated by the application to CMPDT, a CMT.

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References

Campbell, C. P. (1986). ***Criterion referenced performance tests for measuring task proficiency.*** **Knoxille, Tennessee: The University of Tennessee. Technological and Adult Education Department.**

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Carver, R. P. (1974). Two dimensions of test, psychometric and edumetric. *American Psychologist, 29*(7),512-518.

Cheronis, N. S., & Entrikin., J. B. (1963). *Identification of orgnic compounds.* NY: Interscience Publishers, Inc.

Dumas-Carré, A., & Larcher, C. (1987). The stepping of learning and evaluation. *International Journal of Science Education, 9* (1), 93-104.

Fieser, L. F., & Williamson, K. L. (1987). *Organic experiments* (6th ed.). Lexington: D. C. Health and Company.

Gagné, R. M. (1987). *Instructional technology: Foundations.* Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Gay, L. R. (1980). *Educational evaluation and measurement: Compentencies for analysis and application.* Columbus: Charles E. Merrill Publishing Company, A Bell and Howell Company.

Gronlund, N. E. (1982). *Constructing achievement tests* (3rd ed.). Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Herron, J. D., Cantu, L. L., Ward, R., and Srinivasan, V. (1977). Problem associated with concept analysis. *Science Education, 61* (2), 185-199.

Klausmeier, H. J., & Sipple, T. S. (1980). *Learning and teaching concepts. A strategy for testing application of theory.* New York: Academic Press, Inc.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn.* Cambridge: Cambridge University Press.

Popham, W. J. (1978). *Criterion-referenced measurement.* Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Roberts, R. M., Gilbert, J. C., Rodewald, L. B., & Wingrove, A. S. (1974). *An introduction to modern experimental organic chemistry.* NY: Holt, Rinenart and Winston, Inc.

------ (1987). *Modern experimental organic chemistry.* NY: Saunders College Publishing.

Sato, T. (1975). *The construction and interpretation of S-P tables.* Tokyo: Meiji Tosho. (In Japanese)

------ (1980). The S-P chart and the caution index. *NEC Educational Information Bulletin 80-1. C & C System Research Laboratories.* Nippon Electric Co., Ltd.

------ (1986). *Construction and interpretation of S-P chart* (17th Printing). Tokyo: Mei-Ji Books Publisher. (In Japanese)

------ (1988). *The S-P chart analysis.* NEC Technical College, NEC Corporation.

Thorndike, R. L., & Hagen, E. (1969). *Measurement and evaluation in psychology and education.* New York: John Willey and Sons, Inc.

Wang, C. H., & Horng, J. M. (1989). *A design of evaluation tool for achievement in learning melting point determination technique.* Presented at Symposium on NSC Supported Science Education Research, 1989, Taipei, R.O.C.

Williamson, K. L. (1987). *Microscale organic laboratory.* Lexington: D. C. Health and Company.

「熔點測定」技能評量工具之信度與效度

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摘要

在決定標準參照精通評量工具的信度與效度時，傳統的難度指數、區別指數及相關係數的用途不大。本文設計了一個效化過程，首次將S-P表分析法，應用於修訂及效化熔點測定技能標準參照精通評量工具。效化此工具的方法是用(1)前測與後測結果；(2)量表與紙筆測驗結果；(3)工作成果與測驗成績；及(4)在一套合理數目實驗活動中之成果之間的正相關來達成。本研究的結論爲1.對於大二有機化學實驗課程中，一般固體之熔點測定的評量，本工具有滿意內容效度。2.在一套具有代理性合理數目實驗活動的成果，P曲線持續地向下移動，此趨勢顯示出試題的效度。所有試題的CPj值均小於0.20。以Pj對CPj作圖，所有的試題均落在象限A中，這些事實指明所有試題都是良好的。S曲線表示個別學生學習成果的一致性，S曲線持續地向右移動表示了試題有信度。3.此工具的效標關連效度可以由三個S-P表中，P曲線全部持續向下移動觀察出來。對於三個區別性屬性，其D^*值在後測1爲0.2785,在後測2爲0.1965。量表觀察結果與紙筆測驗成績有高的相關(90.9%)。紙筆測驗分數高的學生能準確地測出熔點（具體與確認階層均爲86.4%，歸納階層爲90.9%）。4.對於學習遷移之建構效度，可以從個別學生的(a)工作成果，(b)在一套合理數目活動中的測驗成績及(c)由大一至大二的學習進步情形來看出。5.此工具的信度，可以由(a)S曲線全部持續向右移動，(b)兩套對等形式的測驗有81.8%的一致性看出。(a)和(b)顯示出學習進步的一致性。6.本研究設計了一個包含S-P表分析法（一種無母數方法）的效化過程，能滿意地用於效化標準參照精通評量工具，此可由熔點測定評量工具的效化得到證明。

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Biology Cognitive Preferences of Preservice Biology Teachers

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ABSTRACT

This study developed and validated the *Biology Cognitive Preference Inventory (BCPI)* for investigating the biology cognitive preference styles of students in the biology teacher education program. The internal consistency relibilities of the *BCPI* were 0.95, 0.84, 0.94, and 0.86 for R, P, Q, and A preference areas, respectively. Examination of the stability was also satisfactory. Further analysis of data had demonstrated the support of the concurrent and construct validity of the *BCPI*. It was concluded that the *BCPI* is a reliable and valid instrument for assessing biology cognitive preference styles of biology teachers.

Results of the study revealed that preservice biology teachers exhibited a strong preference for the Q (Questioning) mode and a weak preference for the R (Recall) mode. The rank order of the extent of preference from highest to lowest was Q ---> P, A ---> R. When comparisons of cognitive preference scores among each grade level were made, it was found that juniors and seniors exhibited a slightly stronger preference for R and less preference for Q than did freshmen and sophomores. There were no significant differences between cognitive preferences of male and female subjects. The Q-R dichotomy (scientific curiosity scale) of cognitive preference styles suggested in previous studies was supported by the present study for biology.

The results of data analysis further revealed that no statistically significant correlations were found between biology cognitive preference scores and academic achievement in biology. Scores for P modes correlated positively and weakly with scientific attitudes as measured by the *SAT*.

Key words : biology cognitive preference, scientific attitudes, preservice biology teachers, cognitive preference testing

I. Introduction

Cognitive preferences represent predilections or particular modes a person exhibits to process scientific information (Brown, 1975). This construct was first proposed by Heath (1964) as an alternative dimension to the evaluation of the effects of PSSC, a new science curriculum developed in the 1960s. Its postulation was based upon the hypothesis that, when learning science, students not only acquire scientific knowledge, but also develop particular modes of thinking or preferences in dealing with the scientific knowledge presented to them. Since researches have indicated that cognitive preferences are more or less subject matter dependent, the cognitive preferences of a person may vary from subject to subject and even from area to area within one subject (Rost, 1983; Tamir & Jungwirth, 1984; Tamir & Lunetta, 1978).

In his original research, Heath (1964) suggested four different types of cognitive preference in science. The definitions of the four modes, as adapted from van den Berg (1978), are illustrated as follows.

1. *Factual Information or Recall* (R)

A person responding in this mode likes to store or memorize scientific information in the same

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form it is presented. The "storing" is without any processing such as trying to relate information to other information, or abstracting a general rule or principle from specific data, or questioning the validity of the information. A preference for recall indicates an interest in learning a term, a definition, a fact, an observation, or a concept.

2. *Principles* (P)

A person responding in this mode likes to extract general principles or rules from the information prestented or looks for interrelationships between scientific information. A preference for principles indicates an interest in identifying a relationship between variables, or in learning a rule that can be applied to a class of objects, organisms, phenomena or variables, or an interest in explaining phenomena in terms of general concepts and theories.

3. *Questioning* (Q)

A person responding in this mode likes to evaluate scientific information very critically, looking for limitations and overgeneralizations or suggesting follow-up research. A preference for questioning indicates an interest in critically analyzing and commenting on the validity of scientific information, and/or in generating suggestions and hypotheses for further research.

4. *Applications* (A)

A person responding in this mode tends to evaluate scientific information on its applicability. A preference for applications indicates an interest in using scientific information to solve problems in commerce, industry, farming, in a person's daily life, or in science.

The cognitive preferences exhibited by students in the learning of conventional and inquiry-oriented science curricula were expected to be significantly different. It was hypothesized that students using a "new" science curriculum would possess a higher preference for Principles and Questioning comparing to those who use a more "traditional" one (Heath, 1964; Tamir, 1977a). It is, thus, imperative that assessment of cognitive preferences be included as an indispensable part of science curriculum evaluation. Through such an assessment, science educators can be informed about whether students have developed the modes of preference that a curriculum is said to foster.

The interest of cognitive preference assessment is, as indicated by Heath, "not in whether the student can identify correct and incorrect information but rather in what is he likely to do with information intellectually. If a goal of instruction is to change the students' intellectual style within some academic subject, a test of such achievement must permit him to demonstrate differing styles." Since Heath proposed his idea of cognitive preference testing, several cognitive preference tests have been developed accordingly and used to assess cognitive preferences in science and to explore the relationships between achievement in science and cognitive preferences. However, most of the instruments developed so far were purported to measure the cognitive preferences of students (Kempa & Dube, 1973; Tamir, 1976; 1985; 1988; Tamir & Lunetta, 1978). Very few attempted to focus on those of science teachers.

Cognitive preference tests based upon Heath's notion usually consist of items including an introductory statement followed by four extension alternatives, one for each of the four preference modes. The items within a test are generally in one subject area. The examinees are told that all the four alternatives are correct and are asked to rank or rate the four statements.

During the last two decades, researches have indicated that cognitive preference styles of students may be affected by the interactions between curriculum and teachers' curricular bias (Tamir, 1975; 1977b). Many studies have shown that there are close relationships between science cognitive preferences and achievement in science (Kempa & Dube, 1973; Tamir, 1976; 1977a; Tamir & Kempa, 1978). In general , students who exhibit a strong preference for questioning and application tend to achieve better than students who display a strong preference for memory (Barnett, 1974).

Recently, major science education reforms in this country have attempted to shift learning of science from focusing on memorization of scientific knowledge to emphasizing understanding of fundamental principles and fostering skills related to the acquisition, evaluation and retrieval of scientific knowledge. If this is a success, it is expected that the cognitive preference styles of those students who go through the "new" science programs will exhibit a higher preference for Principles and/or Questioning. Furthermore, studies have also indicated that teachers who exhibited different cognitive preference patterns were found to display different teaching styles which may further produce differences in achievement (Barnett, 1974; Boehlke, 1984). Hence, it is essential for science teacher educators to know whether the science teachers are enabled to possess the desirable cognitive preference styles in science and how the styles are changing through the preservice education program. So far, studies on cognitive preferences have been primarily related to science learning of students. Almost no attempt has been made to investigate the cognitive preference profiles of preservice science teachers. Thus, the purpose of the present study was to develop an instrument for exploring the biology cognitive preference styles of preservice biology teachers and to investigate how biology cognitive preferences are related to scientific attitudes.

II. Methods

The Subjects

The subjects were 143 students from freshmen to seniors in the Department of Biology of National Taiwan Normal University. They are called "preservice biology teachers" in this study.

Development of the BCPI

The construction of the *Biology Cognitive Preference Inventory (BCPI)* was based upon the construct of four cognitive preference modes suggested by Heath (1964). Each item was composed of a statement and four extended responses, each of which represented one of the four cognitive preference modes. The subjects were informed that all responses were correct, and were asked to rank the four responses according to their relative preference by allotting "4" to the most preferred one, "3" and "2" to the next preferred, respectively, and "1" to the least preferred response.

In order to ensure that the subjects were familiar with all the information included in the *BCPI*, the scientific information selected for the development of the items covered only those subjects that were included in the junior- and senior-high biology textbooks. The development of the items was then based upon the selected concepts that were extracted from concept analysis of the biology textbooks. The constructed items were pilot-tried, revised and submitted to a panel of expert judges for evaluation of whether the information associated with all the items was covered in the textbooks and whether each of the responses indeed represented the allocated cognitive preference mode. This greatly enhanced the content validity of the instrument. A typical item is shown below:

* Plasmids found in bacteria have been widely used as a vector in recombinant DNA technique and gene cloning.

(1) R plasmids found in bacteria usually carry antibiotics resistant genes. (R)

(2) Recombinant plasmids which carry genes coded for human insulin can be cloned in bacteria to produce insulin for medical use. (A)

(3) When bacterial cells divide, the plasmids in the cells replicate and separate to the new cells. (P)

(4) It would be interesting to know if inherited human diseases can be cured by recombinant DNA technique. (Q)

After pilot-study and careful revision, 40 items were finally selected for the *BCPI*. The test was administered to the subjects at the beginning of the second semester. The results were then graded ipsatively according to the procedure suggested by Kempa and Dube (1973). That is, for each cognitive preference area, the highest possible score was 160, the lowest possible score was 40 and a random distribution of responses should yield a mean score of 100. The scores were analyzed with an SPSS/PC computer program and validated through examining interpretations of data.

Assessment of Scientific Attitudes

The *Scientific Attitude Test (SAT)*, developed by Cheng and Chou (1990) was used to measure scientific attitudes of the subjects. The *SAT*, as reported by Cheng and Chou, had a coefficient alpha reliability of 0.69 and a test-retest reliability of 0.78. The validity of the test as reported by the same study was fairly satisfactory.

III. Results and Discussion

The Biology Cognitive Preference Inventory (BCPI)

The soundness of the interpretations of a test depends substantially upon the "goodness" of the test validation process. Validation of an instrument calls for an integration of many types of evidence. Cronbach (1951) has contended that a set of test scores is only interpretable when the test possesses substantial internal consistency and when each item in the test measures the same construct as the rest of the items. Hence, in this study, three types of psychometric properties, item characteristics, test reliability, and test validity, were examined.

The item characteristics were produced by item analysis. Item analysis was commonly carried out by examining the item-scale correlation of each item. An item with satisfactory item-scale correlation is said to have favorable discriminating power, and must contribute to the internal consistency and validity of the test. An item-scale correlation is a part-whole correlation and thus, can be greatly exaggerated because the item's specific and error variances also contribute to the correlation. This situation is particularly true in a test of limited length. Therefore, in the present study, item-scale correlation between an item and the composite of the remaining items of the part to which that item belongs was calculated to remove the spuriously inflated estimation of correlation (Guilford & Fruchter, 1978, pp. 465-467).

Table 1 presents the average values of *corrected* item-scale correlations of the 40 statements for each of the four preference modes. Out of a total of 160 correlation coefficients calculated, only 13 coefficients (5 from P mode, 1 from Q mode and 7 from A mode) did not reach the 0.05 significant level. The means of item-scale correlations for the R, P, Q, and A modes were 0.54, 0.32, 0.51, and 0.34, respectively. Since these values were item-remainder correlations, they were considered high and satisfactory. These data indicated that each preference statement contributed well to the internal consistency of the part to which that statement belonged. This analysis accorded perfectly with the changes of coefficient alpha of the part when that statement was depleted (Data not shown).

Additional evidence which has often been used to support the internal consistency of a test comes from examining the profile of inter-item correlations, since the larger the inter-item correlations, the greater is the internal consistency (Guilford & Fruchter, 1978, p.424). The means of inter-item correlations for R, P, Q, and A preference modes were 0.31, 0.11, 0.28, and 0.14, respectively (Also see Table 1). Given the situation that the values for modes P and A were slightly lower than the other two modes, one may predict that the internal consistency reliability of the two modes would not be as high as those of R and Q modes.

Table 1. The Means and Standard Deviations of Corrected Item-Total (r_{it}) and Interitem (r_{ii}) Correlations of the 40 Items in Each Preference Mode

Preference Areas		R	P	Q	A
r_{it}	Mean	0.54	0.32	0.51	0.34
	SD	0.13	0.13	0.15	0.17
r_{ii}	Mean	0.31	0.11	0.28	0.14
	SD	0.12	0.13	0.14	0.15

Reliability

Two types of reliability, internal consistency and stability, were examined in the present study. Cronbach coefficient alpha was computed to evaluate the internal consistency of the *BCPI*. The reliability coefficients obtained for the entire group of subjects were 0.95, 0.84, 0.94, and 0.86 for R, P, Q, and A modes, respectively (Table 2). These values were higher than those reported in the literature (Tamir, 1985), and hence, they were considered very satisfactory because the primary concern of cognitive preference testing in this study was with group comparisons rather than individual discrimination. The rest of the reliability values in Table 2, which ranged from 0.80 to 0.96, were also regarded as very satisfactory when compared with those reported in the literature.

The stability reliability of the *BCPI* was examined by calculating the correlations between test and retest scores of seniors with a 2 to 3-week interval. The coefficients obtained were 0.82, 0.76, 0.85, and 0.72 for R, P, Q, and A modes, respectively.

Table 2. Coefficient Alpha of the BCPI Scores

Preference Areas	N	R	P	Q	A
Total Sample	143	0.95	0.84	0.94	0.86
Freshman	27	0.93	0.80	0.93	0.85
Sophomore	30	0.90	0.81	0.93	0.82
Junior	36	0.93	0.86	0.92	0.89
Senior	50	0.96	0.85	0.95	0.87

Validity

Three aspects of validity, namely content, concurrent and construct validity, were examined for validation of the *BCPI*. Content validity was established on the basis of the following claims. As indicated previously, an analysis of the subject matter content of the biology curricula currently used in secondary schools has been carried out to ensure that the subjects of the present study were familiar with all scientific information covered in the test. In addition, for each item of the *BCPI* , the allocation of each option to one of the four cognitive preference areas was determined by a panel of expert judges and only those items for which complete consensus was reached were retained.

Concurrent validity was examined by correlating the *BCPI* scores with *BCPT* scores (Tamir, 1975). The correlations between each of the four corresponding

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preference areas, which ranged from 0.26 to 0.72, were considered slightly low (Table 3). This was particularly true in the Q preference mode. Among the 40 items of the *BCPT*, half called for ratings of the four preference options rather than rankings. This might explain the low correlations obtained.

Construct validity was investigated by integrating the findings to examine whether the *BCPI* measured the attribute it is said to measure and to see whether the scores obtained were consistent with the proposed interpretations. This process was operationally supported by the following data analysis and the interpretations herein made.

Table 3. Pearson Product-Moment Correlations Between BCPI and BCPT Scores (N=23)

	BCPI		BCPT		
	Mean	SD	Mean	SD	r
R : R	79.22	(25.24)	104.52	(13.65)	0.38
P : P	107.22	(16.57)	115.91	(11.69)	0.41•
Q : Q	114.91	(27.89)	104.70	(14.48)	0.26
A : A	98.65	(13.94)	100.35	(10.48)	0.72•

• Significant at the 0.05 level

Cognitive Preference Styles of Preservice Biology Teachers

In the present study, the cognitive preference scores are ipsative (ranking) in nature. This means an individual's scores on the four preference modes are interdependent; hence, the normal procedure for interpreting correlation coefficients can not be applied. It was thus expected that some of the correlation coefficients among the four cognitive preference scores would be negative.

The intercorrelations among the four cognitive preference modes are presented in Table 4. Correlations between Q-R and P-A modes were strongly negative with coefficients of -0.89 and -0.72, respectively. Medially negative correlations were also found between R-A and P-Q modes with coefficients of -0.56 and -0.55, respectively. The remaining coefficients, 0.44 for R-P pair and 0.32 for Q-A pair, were positive and somewhat lower. These results show that two main opposite scales, the Q-R and the P-A scales, may exist within the four cognitive preference areas. These findings partially support the two dichotomies (Q-R, P-A) in cognitive preferences identified by Kempa and Dube (1973). The two scales have been termed "scientific curiosity scale" and "scientific utility scale", respectively (Kempa and Dube, 1973; Tamir, 1975).

Although the ipsative procedure has raised some doubts regarding the validity of the data obtained, Tamir and Lunetta (1977) have given strong support to the use of the ipsative procedure in the study of science cognitive preference. They found that the two dichotomies in cognitive preference also existed in the studies using normative procedures. They further indicated that the ipsative procedure discriminated more clearly between different cognitive patterns and that the danger of distorted relationships is not as severe as might be expected.

Table 4. Intercorrelations of Scores in Biology Cognitive Preference Areas (N=143)

	R	P	Q
Recall (R)			
Principles(P)	0.44••		
Questioning(Q)	-0.89••	-0.55••	
Application(A)	-0.56••	-0.72••	0.32••

•• P<0.01

The means and standard deviations of scores obtained for the four cognitive preference modes are shown in Table 5. When the means of the scores of the four preference modes are compared, three distinct levels of preferences can be found. The rank order of mean scores from the highest preference to the lowest preference was Q ---> P, A ---> R for the total subjects as well as for the four grade levels. It may, thus, be concluded that the subjects exhibited a strong preference for the Q (Questioning) mode and a very low preference for the R (Recall) mode.

It is worth noting the fact that cognitive preference testing has added a remarkable dimension to the evaluation of educational attainment of a science education program (Heath, 1964; Rost, 1983). It should also be a useful device for studying the effects of an educational program on cognitive preference styles of presevice teachers. If nurturing a cognitive preference style characterized by a strong preference for Questioning and Principles and a weak preference for Recall is a major goal for biology teacher education, then the results of the present study have already provided substantial and favorable support to success in this endeavor.

When a close examination of the data presented in Table 5 was made, it could be seen that the mean scores of the R mode increased gradually with grade levels, while the mean scores of the Q mode decreased

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with a distinct drop between sophomore and junior levels. Yet no significant changes were found in the mean scores of the P and A modes over the four grade levels. This may indicate that preservice biology teachers tend to exhibit an increasing preference for memorization and less preference for questioning of biological information when they reach the higher grade levels.

Also shown in Table 5, the Q - R (Q minus R) values decreased steeply from freshmen to seniors with a big drop between sophomore and junior levels. What do these results mean where trends in biology cognitive preferences are concerned? The explanations for these phenomena are subjected to disputation. The high positive Q - R score pattern, as stated by Kempa and Dube, "may be taken as an indication of a student's willingness and desire to acquire scientific knowledge beyond that already possessed" (p.287). However, Jungwirth (1980) has challenged the validity of this explanation and has given an alternative interpretation of this bipolar Q-R phenomenon. Jungwirth contended that respondents' level of familiarity with content might play a role. In the present study, Jungwirth's interpretation seems to be a more suitable explanation of the data obtained. Thus, the decrease in Q - R values with grade levels may be interpreted as an indication that juniors and seniors possess a higher degree of familiarity with the subject matter content of the *BCPI* than do freshmen and sophomores.

Table 5. Means and Standard Deviations (Parentheses) of the BCPI Scores for Each Grade Level

	Total Sample	Freshman	Sophomore	Junior	Senior
N =	143	27	30	36	50
R	81.92 (24.96)	72.78 (20.23)	75.93 (18.78)	83.81 (23.11)	89.08 (29.58)
P	102.08 (14.51)	99.15 (12.38)	102.07 (12.85)	102.31 (16.08)	103.50 (15.47)
Q	114.26 (24.87)	122.89 (21.25)	122.17 (22.69)	109.58 (22.22)	108.22 (27.63)
A	101.72 (16.41)	105.11 (15.30)	99.77 (13.78)	104.31 (18.50)	99.20 (16.72)
Q - R	32.34	50.11	46.24	25.77	19.14

One-way ANOVA of scores for each cognitive preference area indicated that statistically significant differences among different grade levels existed in the R and Q modes (Table 6 and 7). The subsequent multiple-range tests further indicated that the mean score of seniors for the R mode was significantly higher than those of freshmen and sophomores. The mean scores of juniors and seniors for the Q mode were significantly lower than those of freshmen and sophomores. It is concluded that seniors and juniors exhibit higher preference for Recall and lower preference for Questioning than do freshmen and sophomores. No statistically significant differences were found among the mean scores for the P and A modes of different grade levels.

Table 6. Summary of ANOVA of the BCPI-R Scores by Grade Level

Source	df	SS	MS	F	F Prob.
Between Groups	3	6023.14	2007.71	3.39	0.020
Within Groups	139	82423.85	592.98		
Total	142	88446.99			

Comparisons Between Each Pair of Means

	Groups	N	Mean	1	2	3
1	Freshman	27	72.78			
2	Sophomore	30	75.93			
3	Junior	36	83.81			
4	Senior	50	89.08	*	*	

* Significant at the 0.05 level.

When comparisons of the biology cognitive preferences of male and female subjects are made, the results show that no statistically significant differences can be found among any of the four preference areas (Table 8). The findings are different from those reported in previous studies, in which differences in cognitive preferences between 12th grade (Tamir, 1975), and 10th grade (Tamir & Kempa, 1978) male and female students were found. However, the results of the present study are in full agreement with Tamir's (1988) most recent report in which a group of Israeli 12th grade students were studied.

The Cognitive Preferences and Scientific Attitudes

In the previous studies (Kempa & Dube, 1973; Tamir & Kempa, 1977), two cognitive preference orientation scales, namely "Scientific curiosity" (Q-R) and "Scientific utility" (P-A), have been identified. It may, thus, imply a need for this study to investigate

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Table 7. Summary of ANOVA of the BCPI-Q Scores by Grade Level

Source	df	SS	MS	F	F Prob.
Between Groups	3	6497.26	2165.75	3.70	0.013
Within Groups	139	81360.16	585.32		
Total	142	87857.42			

Comparisons Between Each Pair of Means

	Groups	N	Mean	1	2	3
1	Freshman	27	122.89			
2	Sophomore	30	122.17			
3	Junior	36	109.58	*	*	
4	Senior	50	108.22	*	*	

* Significant at the 0.05 level.

Table 8. Comparisons of the BCPI Mean Scores Between Male and Female Subjects

Preference Area	Male (N=58)		Female (N=85)		t Prob.
	Mean	SD	Mean	SD	
R	82.00	27.63	81.86	23.13	0.975
P	102.09	14.08	102.07	14.87	0.995
Q	113.33	27.33	114.89	23.20	0.721
A	102.59	17.03	101.13	16.05	0.608

the relationships between cognitive preferences and scientific attitudes of the subjects.

The relationships among biology cognitive preferences, scientific attitudes, and academic achievements are presented in Table 9. No statistically significant correlations are found between cognitive preference scores and academic achievement scores as represented by the sum of seven semester means. As far as the correlations between cognitive preferences and scientific attitudes as measured by the *SAT* are concerned, it can be seen that scores for P modes correlate positively with scientific attitude scores. No statistically significant correlations are found between scores of the other three modes and scientific attitude.

If the subjects are further grouped into high (H, above +1.0 SD), medium (M, from -1.0 to +1.0 SD), and low (L, below -1.0 SD) categories according to the *SAT* scores obtained, comparisons of biology cognitive preference scores among the three groups of subjects reveal that the high group exhibited significantly stronger preference for the P mode and weaker preference for the A mode than did the other two groups (Table 10), while, in the R mode, the low group scored significantly higher than the medium group. These results indicate that the three groups of subjects exhibited different cognitive preference styles in biology.

Table 9. Correlations Between BCPI Scores with Scientific Attitudes (SAT) and Academic Achievement (AA) Scores (N=48)

Preference Area	R	P	Q	A
SAT Score	-0.226	0.302*	0.175	-0.177
AA Score	-0.040	0.205	-0.013	-0.102

* Significant at the 0.05 level.

Table 10. Differences in Cognitive Preferences among Three Groups of Subjects Categorized by SAT Scores

Preference Area		SAT Score Category#			F Prob. (df:2,137)	MRT*
		H (N=24)	M (N=92)	L (N=24)		
R	Mean	85.25	77.83	94.13	0.011	M:L
	SD	28.83	23.18	21.66		
P	Mean	110.54	101.14	98.33	0.006	H:M,H:L
	SD	13.05	13.98	15.26		
Q	Mean	110.71	117.58	104.58	0.052	M:L
	SD	26.38	24.31	21.56		
A	Mean	93.50	103.42	102.92	0.028	H:M,H:L
	SD	18.05	16.27	13.76		
SAT	Mean	37.25	32.10	24.38		
	SD	1.22	2.17	2.18		

# H, L, and M represent above +1 SD, below -1 SD, and in between, respectively.

* In MRT (Multiple Range Test), only pairs of groups significantly different at the 0.05 level are reported.

IV. Conclusions

In this study, the biology cognitive preference styles of preservice biology teachers were studied using

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a self-developed biology cognitive preference inventory. Following are the main findings:

1. Evidence has suggested that the *BCPI* is a reliable and valid instrument for assessing biology cognitive preference styles of preservice biology teachers.
2. The *BCPI* can be used to assess the effects of a curriculum or educational program on students' cognitive preference styles in biology.
3. Preservice biology teachers exhibited a strong preference for the Q (Questioning) mode and a very weak preference for the R (Recall) mode. The rank order of the level of preference from highest to lowest was Q ---> P, A ---> R.
4. Seniors and juniors exhibited slightly stronger preference for R and less preference for Q than did freshmen and sophomores. No statistically significant differences could be found on the extent of preference for the P (Principles) and A (Application) modes among the four grade levels.
5. No significant differences in biology cognitive preferences could be found between male and female subjects.
6. The Q-R dichotomy (scientific curiosity scale) of cognitive preference style for chemistry suggested in previous studies was supported by the present study for biology.
7. No statistically significant correlations were found between cognitive preferences in biology and academic achievement as represented by the sum of seven semester means.
8. Scores for the P preference mode correlated positively but weakly with scientific attitudes as measured by the *SAT*.

V. Implications for Further .Research

Due to the potential of revealing the cognitive mode a person born intellectually in attending scientific information, cognitive preference testing appears to be a promising field of research in science education in general and science teacher education specifically. It is hoped that whether the stated goals of a science teacher education program are being achieved can be examined through investigating the cognitive preference styles of pre- and in-service science teachers. As a result of the present study, the following implications are suggested for further research.

1. Since Heath proposed the construct of cognitive preference, the main criticisms of cognitive preference testing have been mostly related to construct validity. Therefore, more research focusing on different disciplines or even different content areas in a single discipline and employing a variety of subjects is required in order to provide additional evidence for establishing consturct validity of cognitive preference testing.
2. The limitations of ipsative data produced in most cognitive preference studies have called for special caution in analyzing and interpreting research results. Therefore, the question of whether cognitive preference data is indeed ipsative in nature needs to be further investigated.
3. More studies need to be done in order to see whether it is possible and desirable for science teacher educators to nurture a specific cognitive preference style in science teachers.
4. It would be interesting to explore what differences in cognitive preference styles exist among science teachers with different educational background and majors, and how science cognitive preference styles influence teaching behavior as well as student achievement in science.
5. It would also be interesting and perhaps necessary to study what science teachers do, or could do, to influence the science cognitive preferences of their students.

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References

Barnett, H.C. (1974). An investigation of relationships among biology achievement, perception of teacher style, and cognitive preferences. *Journal of Research in Science Teaching, 11* (2), 141-147.

Boehlke, P.R. (1984). *Cognitive preferences and science teaching behavior*. Unpublished doctoral dissertation, The University of Iowa.

Brown, S.A. (1975). Cognitive preferences in science: Their nature and analysis. *Studies in Science Education, 2* , 43-65.

Cheng, Y.J. & Chou, H.M. (1990). A study on the scientific attitudes of preservice biology teachers. *Bulletin of National Taiwan Normal University, 35*, 249-270.

Cronbach, L.J. (1951). Coefficient alpha and the internal structure of test. *Psychometrika, 16*, 297-334.

Guilford, J.P. & Fruchter, B. (1978). *Fundamental Statistics in Psychology and Education*. Sixth edition. NY: McGraw-Hill Book Company.

Heath, R.W. (1964). Curriculum, cognition, and educational measurement. *Educational and Psychological Measurement, 24* (2), 239-253.

Jungwirth, E. (1980). Alternative interpretations of findings in cognitive preference research in science education. *Science*

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Education, 64 (1), 85-94.

Kempa, R.F. & Dube, G.E. (1973). Cognitive preference orientations in students of chemistry. *British Journal of Educational Psychology, 43*, 279-288.

Rost, J. (1983). Cognitive preferences as components of student interest. *Studies in Educational Evaluation, 9*, 285-302.

Tamir, P. (1975). The relationship among cognitive preference, school environment, teacher' curricular bias, curriculum, and subject matter. *American Educational Research Journal, 12* (3), 235-264.

------ (1976). The relationship between achievement in biology and cognitive preferences styles in high school students. *British Journal Educational Psychology, 46*, 57-67.

------ (1977a). A note on cognitive preferences in science. *Studies in Science Education, 4*, 111-121.

------ (1977b). The relationship between cognitive preferences of students and their teachers. *Journal of Curriculum Studies, 9* (1), 67-74.

------ (1985). Meta-analysis of cognitive preferences and learning. *Journal of Research in Science Teaching, 22* (1), 1-17.

------ (1988). The relationship between cognitive preferences, student background and achievement in science. *Journal of Research in Science Teaching, 25* (3), 201-216.

Tamir, P. & Jungwirth, E. (1984). Test scores and associations as measures of cognitive preferences. *Studies in Educational Evaluation, 10*, 149-158.

Tamir, P. & Kempa, R.F. (1977). College students' cognitive preferences in science. *The Journal of Educational Research, 70*, 210-218.

------ (1978). Cognitive preference styles across three science disciplines. *Science Education, 62* (2), 143-152.

Tamir, P. & Lunetta, V.N. (1977). A comparison of ipsative and normative procedures in the study of cognitive preferences. *The Journal of Educational Research, 71*, 86-92.

------ (1978). Cognitive preferences in biology of a group of talented high school students. *Journal of Research in Science Teaching, 15* (1), 59-64.

van den Berg, E. (1978). *Cognitive Preferences: A Validation Study.* Unpublished doctoral dissertation, The University of Iowa.

職前生物教師的生物認知偏好

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摘　要

本研究發展並效化「生物認知偏好調查表」(BCPI)，並藉之探索職前生物教師之生物認知偏好風格。研究結果顯示，BCPI之R、P、Q、A四類認知偏好分數之「內部均質性信度」分別爲0.95, 0.84, 0.94和0.86，穩定信度亦稱理想。同時效度和構念效度的考驗亦均十分理想。結果顯示BCPI爲一可信、有效的生物認知偏好評測工具。

職前生物教師的生物認知偏好風格顯示出強烈的Q（質疑）偏好，較弱的R(記憶）偏好。其對R、P、Q、A四種型式的偏好程度，依高低順序排列爲Q→P、A→R。就年級言，三、四年級學生的R偏好比一、二年級學生稍微強些，而Q偏好則稍微弱些。本研究的結果同時也證實了生物認知偏好風格中，有Q-R（科學好奇心）向度的存在。此外男女職前生物教師的生物認知偏好風格並無顯著差異存在。

研究結果同時亦顯示，職前生物教師的生物認知偏好與學業成就之間並無顯著相關存在。生物認知偏好之P偏好分數與科學態度之間則有低度正相關存在，其餘三項偏好分數與科學態度之間則無顯著相關存在。

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Search for Indicative Items in the Developmental Study of Test Instruments

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ABSTRACT

Under the constraints of limited time and number of items to be tested in a standardized test for process skills, each item of the test is supposed to be indicative enough to reflect the different ability levels of examinees; meanwhile, examinees with the same ability should display as similar a response pattern as possible among those indicative items.

Over 3 years of study in the development of tools for testing the abilities in "interpreting data" for students in our country the author has used two additional approaches besides the traditional method of panel evaluation in selecting indicative items: (A) By longitudinal and cross-sectional study of the responses of examinees, the data of the same idividuals were analysed to verify whether or not the selected items were indicative; (B) By applying SOLO Taxonomy for the design of structured questions to classify the level of performance of examinees, the responses were analysed to investigate the degree of consistency in the order of levels as predicted by SOLO Taxonomy.

The results of approach (A) show that the response patterns were very consistent in many respects when the indicative items were selected after several years of observations. On the other hand, results of approach (B) show that structured questions designed according to the description of SOLO Taxonomy may be used to differentiate the abilities of examinees, yet are not sufficient to define the true ability of the examinees only through the responses found to a single question. As a result, there are still some modifications that need to be made and attempts for further investigation need to be taken in future study.

Key words: indicative items, interpreting data, process skills, development

I. Introduction

During 3 years of study in the development of tools for testing process skills, especially in the subtest "interpreting data", the author was inevitably confronted with many problems which needed to be reviewed for futher applications. This paper will restrict its discussion to the search for indicative items, and the author's personal findings in developmental study on a test tool for interpreting data will be used as an illustration.

In the process of standardization of tools, there are many administrative constraints, such as time limitation, and hence, the test length or number of items; therefore, the search for adequate indicative items to assure the validity of content and the validity of construct becomes a "must". Yet, content validity and the construct validity usually rely heavily upon the expert's subjective point of view. For instance, there are various methods of definition in interpreting data, all of which are too subjective and restricted in certain domains, as shown in the widely used process skill test tool "TIPS I" and "TIPS II". There one can only find the skill of interpreting data/graphs

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confined to "identifying a graph that represents the data" and "identifying the relationship between the variables in a given graph of data" (Dillahaw Okey, 1980; Burns, *et al.*, 1985). Are these objectives sufficient to display the ability to interpret data? Could there be better ways to represent the ability concerned? In other words, are certain "line spectra" or indicative items to better reflect ability in the domain of interpreting data which could be found to reveal the ability more satisfactorily?

In order to determine the scope or domain of the item universe in the related skill, there are, theoretically, two different approaches; top-down task analysis(Gagne, 1961) and bottom-up understanding of the thinking of the child(CSMS,1980), which has it's root in Piaget's type of research. Both are essential to the development of an instrument with good construct validity.

Underlying this search for indicative test items, two assumptions have been made as follows:

(1) There exist certain ability levels that can reveal the different levels of student's cognitive development, just as with temperature measurement in physics.

(2) Those levels can be found only if the test items are well constructed and their levels of difficulty are ordered according to their ability levels as in the case of radiation of line spectra of a certain substance under the increasing input of energy.

To attain the presumed goals, i.e., to search for more indicative items that can better calibrate the scale of ability to interpret data, manifold efforts had been made (Mau,1987, 1988, 1989) during the last three years.

(1) To find the prerequisite basis of the process skills of interpretation of data, such as reading from curves in various situations.

(2) To find the fine-structure of the related contents, i.e., to determine the variety of responses within the same content. For example, there are many aspects of describing data given as curves, namely, the significance of an intercept, the meaning of "level-off" in a curve, the increment or the tendency as shown by the curve, and the relationship between two curves, etc.

(3) To confirm the hierachical structure of the related contents as found in the previous study, i.e., consistency in the order of facility or difficulty of items as shown by the responses of students of different grades as well as by the same individuals during different years' tests through cross sectional and longitudinal studies.

In the search for indicative test-items, two different approaches are to be reviewed:

(A) In order to find items indicative of a student's ability to describe data given as curves, the results of longitudinal study of responses with respect to selected items among the samples over the preceeding 3 years' continuous study projects will be discussed.

(B) In order to find higher level ability to interpret data, the test items ought to be open-ended to allow student to respond according to their ability; hence, the "response description" established by "The SOLO Taxonomy" (Biggs & Collis;1982) was tried in constructing items of more sophisticated nature, and at a higher difficulty level, such as in the domain of comparison of common attributes, the relation shown in a curve and the generalization of data, etc. Preliminary results of the pilot test will also be discussed.

II. Background

In a review of assessment instruments in science, Mayer and Richmond(1982) noted the increase in the use of process-oriented tests since the 1960s. Tannenbaum(1968), Burns(1972), Riley(1972), Mcleod *et al.* (1975), Ludeman(1975), Molitor and George(1976), Dillashaw and Okey (1980), Tobin and Capie(1982), Burns and Okey(1985) all made contributions in the development of process-skill test tools for different purposes. Their construction of test tools all had some things in common. In the process of development, they set the criteria or objectives for a test in advance, and the test items (usually in multiple choice format) were then designed accordingly. Also, the descriptions of the objectives written related only to a certain part of the contents of the process skills. Those objectives might result from certain analysis of the contents or curricula to be assessed. This way of developing the test items had to do with the idea of rational task analysis used by Gagne(1961). He had also proposed the idea of a learning hierarchy. To Gagne, learning hierarchies are characterised as "an ordered set of intellectual skills such that each entity generates a substantial amount of positive transfer to the learning of a not previously acquired higher-order capability".

He also suggested that the hierarchy can be checked empirically for positive transfer by taking as a hypothesis that an individual will be able to learn a particular topic that supports it. This way of analysis can be very helpful in the setting up indicative criteria for test purposes if and only if the logical structure can be found and the actual way of thinking of children or their ability level can be well detected.

On the other hand, Piaget's type of research implies that a hierarchy of understanding in process skills cannot be identified simply by examining the

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logical structure of process skills or by analysing a given concept as a network of prerequisite concepts or skills.

The claims made by the piagetian school of research would seem to base the hierarchy of understanding on the responses of children. The responses are categorized and are judged to be indicative of certain modes of thought.

Biggs and Collis(1982), based initially on the cognitive literature, went a step further to devise a model of evaluation which enabled a child's answer to a particular question to be classified by SOLO Taxonomy. According to their model, there are five basic categories most suitable for evaluating the structural complexity of responses in an open-ended question; the questions have to be formulated so that a correct response to a specific question shows an ability to respond at a particular SOLO level.

However, some people perform on a test or answer a question more consistently than others, and that consistency varies with ability. In view of this, the performance of high-ability examinees on several parallel forms of a test might be expected to be more consistent than the performance of medium-ability examinees. Therefore the probability that an examinee will answer a particular question correctly is of considerable value when adapting a test to match the examinee's ability level. The ideas thus derived from the item response theory were worked out in the contributions of Rasch (1960), Wright (1967,1979), Lord (1968,1974,1980) and others. The decisive idea on which the Rasch model for item analysis and test construction is based is that probability of success is determined by the person's ability and the item's difficulty. That is to say, a more able person is supposed always to have a greater chance of success on any item than a less able person. This idea will be used to find the items that are discriminative and indicative of abilities, and all serve to cross-examine the SOLO level or the order of difficulty in this pilot study.

III. Procedures

(A) In the longitudinal study, several major steps were taken as follows:

(1) The selection of items in the domain of describing data given as curves found in the previous year's study showed that a fair description of the comparison of a two curve problem concerning the relationship of the curves and their rate of change is not easy for junior high school students; therefore, this study discusses the following clusters of items(R2) as indicative items.

The R2 group included items B44, C30, C24, C29(as illustrated in the appendix I), and B26 (both B44 and B26 were answered by the same individuals of this sample last year and B26 was typically similar to C24 and C29, while B44 showed a significant difference in difficulty between the dif-ferent grades). The R2 group is designed to test the ability to describe the relationship between two curves.

The S group included items C11, C10, and B10 (B10 was also answered last year by the same individuals of this sample, and is identical to C10, while C11 is similar to C10). The S group is designed to test the ability to compare the rate of change of the curve. This will not be discussed in this paper.

Cluster	Group	Indicative items selected this year		The other relative items in the same item group
		New items	Corresponding items tested also last year	
X23	R 2	C24.C29 C30	B26 B44	C21.C22.C27.C28
	S	C10.C11	B10	C7.C8.C9.C31.C32
X16	I	C1 C39	B1 B46	C5.C9.C20.C34.C35. C36
	T	C2 C38	B2 B45	C6.C12.C23.C37
X45	R 3			C40.C41.C42.C43.C44

In addition, there are 9 more items all related to the description of data given in various curves. Altogether there are 17 items to form the X23 cluster in the domain of describing data in given curves. The entire test consists of 44 items, including clusters X16 (reading off data from the given curve), X45(the ration test) and R3(the generalization group). However this paper is interested only in discussion in the domain of describing data(R2).

(2) The subjects chosen for longitational study were students who had taken part in the two previous years in the Taipei area (2 schools in the downtown area, 2 in other parts of the city, and 2 in suburban areas). The total number of students is 223 (114 for grade 8, which were formerly in grade 7, and 109 for grade 9, which were formerly in grade 8) out of 515 samples tested the previous year, respectively, for each grade.

(3) The reliability was calculated in Kr20 for the entire test. The correlation between X23 and the total score of this test, and student's school achievement test in mathematics and physical science was also calculated.

(B) The major procedures of the pilot test in the application of SOLO Taxonomy for the construction of test items for higher level ability to interpret data were as follows:

(1) The setting up of suitable criteria and the construction of questions according to SOLO response description.

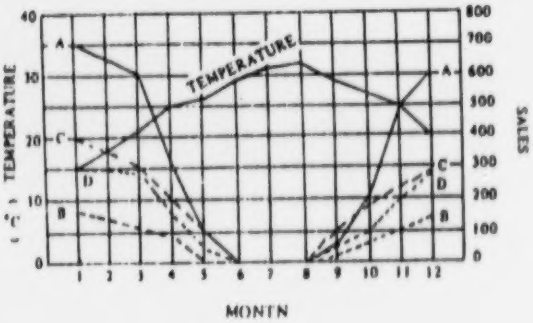
Table 1. SOLO Taxonomy and the criteria adopted in the pilot test

SOLO Description	The criteria adopted
Prestructural (single piece of irrelevant or appropriate information used)	This catagory was not adopted by this pilot test.
Unistructural (single piece of relevant information used)	This catagory with its criteria was adopted to form the items of finding out the characteristic feature of curves given in various questions (Q3, Q5, Q7).
Multistructural (several pieces of relevent information used but pieces not related)	This catagory with its criteria was adopted to form the succeeding item of each question to ask for the finding of common features among the curves given in Q3, Q5, Q7, respectively.
Relational (all available information used and inter-related)	This catagory with its criteria was adopted to form the items of R2 group (describing the relationship between the curves as given in Q3, Q5, and Q7).
Extented abstract (all available information used inter-related and tested against abstract construct suggested by the data)	This catagory with its criteria was adopted to form the items of generalizing the information among the curves given in Q3, Q5, Q7.

Item A15 together with items A7, A23, A29, and A36 in other questions were grouped to form the R2 cluster to cross examine the ability to describe relationships betweeen the various curves given in different questions.

There are 5 items in question 3 for instance, constructed as follows,

Q3 : The following curves in the graph show the relationship between temperature and the sales of different kinds of sweaters. Look at it carefully and answer the following questions.



Unistructural :

Item A14 : Which kind of sweater has the best sales in September? ________________
and which kind of sweater has the best sales for the whole year? __________

Relational :

Item A15 : What is the relationship between temperature and the sales of sweater A?
____

Multistructural :

Item A16 : What are the common features of sweater A, B, and C in their sales?

Extended abstract :

Item A17 : There is an another kind of sweater, imported from a foreign country, plot the pattern of its sales curve in the graph, to show its relationship between the amount of sales and the month of the year.

Item A18 : State the reason for your plot.
____

Since the author is interested firstly in this pilot test in finding out whether or not the question concerning higher ability to interpret data so constructed according to SOLO Taxonomy could be effective enough to show whether the responses of students are consistent with their abilities, question 3 as illustrated above will be reviewed first. The whole test consists of 40 items arranged in 7 questions, and questions 3, 5, and 7, following the creteria suggested by SOLO taxonomy, are similar in construction but different in content.

(2) The subjects (502 in grade 7; 507 in grade 8;

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407 in grade 9) in this pilot test were the students of an entire school with their students' IQ data available for further correlation analysis.

(3) The reliability of this pilot test was also calculated in Kr20 with results of .8380(grade 7), .8631(grade 8) and .8830(grade 9). In addition, the mean of the pilot test and their achievement tests together with the correlation between groups and within groups was also calculated.

(4) For the questions constructed according to SOLO Taxonomy as illustrated in question 3, and for the items of the R2 group (describing the relationship) in this pilot test, their response pattern and the T-value (two tail problem) will be first investigated to see whether there are some signigicant differences within different abilities.

Table 2. The correlation between X23 and the total score, etc., with their reliability coefficients.

GRADE 8 :

Correlations :	X16	X23	X45	X7
CT(total score)	.9461••	.9236••	.6695••	.7083••
MATH	.5123••	.5612••	.5291••	.2667••
PHY	.6842••	.6698••	.6937••	.4724••

N of cases : 113 Significance : • - .01 •• - .001

GRADE 9 :

Correlations :	X16	X23	X45	X7
CT(total score)	.9364••	.9143••	.6879••	.5939••
MATH	.5703••	.4439••	.5251••	.1872••
PHY	.5158••	.4719••	.3989••	.2054••
EARS	.5241••	.5398••	.4114••	.3769••

N of cases : 109 Significance : • - .01 •• - .001

Kr20 of	total score	X16	X23	X45	X7
GRADE 9	.9264	.8791	.8270	.8186	.6023
GRADE 8	.9447	.9096	.9260	.8363	.7238

IV. Results and Discussion

The results of two different approaches for the development of indicative items in describing the relationship of data are as follows:

(A) In the longitudinal study.

The reliability of the test shown by the data of Kr20 coefficients and internal consistency shown by their correlations are all satisfactory.

(1) For those selected tentatively as the indicative items (C24, C29, C30, B26, B44) of the R2 group, the results of the t-test between the following samples are significant.

1a. The t-test results between those who accomplished the entire 5 indicative items and those who failed, whether in the total score of the last test(CT), in the x23 cluster(17 items all related to the various levels of abilities to describe the data given in different curves), or in their achievement test in math and physical science, all show significant differences, both in grade 8 students and in grade 9 students. This also shows clearly that the more able students, as shown in their achievement tests and the total scores of this test, were more successful in answering correctly the X23 cluster (i.e., if they had the ability to answer the above 5 indicative items, they were more successful with the problems in the X23 cluster). Hence, the 5 selected items could be used to differentiate ability to describe data given as curves for either grade 8 or grade 9.

1b. However, the t-test results between students in grade 8 and in grade 9, by whom the total 5 selected items were all accomplished, shows no significant difference. This result also implies that those who are able to answer correctly the 5 selected items desplayed similar ability to handle the problems of the X23 cluster and the total test regardless of their grade. Hence, the selected items could be considered to be indicative in discriminating those who have the ability

Table 3. The t-test in many aspects between those who accomplished the selected items and/or failed in grade 8 or 9

	MATH	PHY	CT	X23
between those who accomplished and those who failed (GRADE 8)	7.09/.000	9.71/.000	14.56/.000	12.77/.000
between those who accomplished and those who failed(GRADE 9)	7.99/.000	4.91/.000	14.14/.000	15.34/.000
between GRADE 8 and GRADE 9(all accompished)	.29/.777•	.43/.672•	-.63/.538•	.21/.836•

• : There is no significant difference

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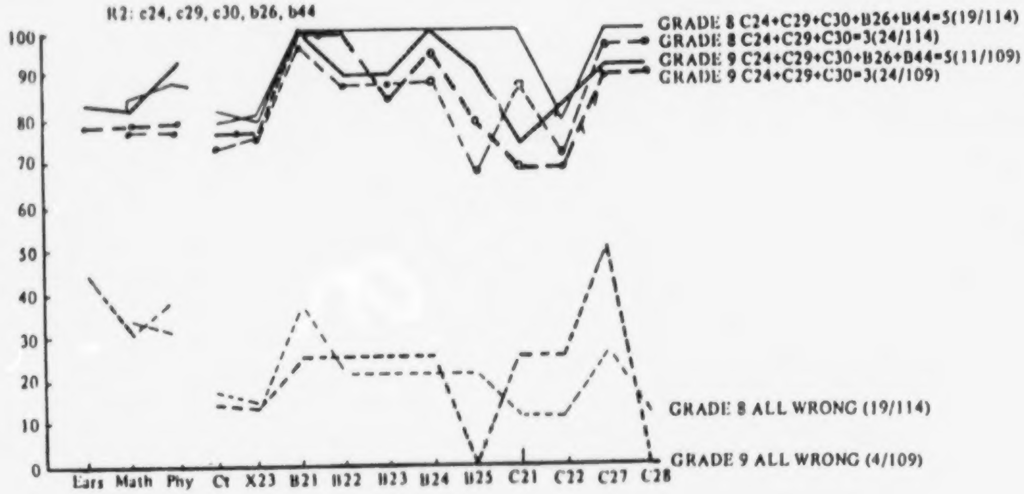
and those who don't, and once they have the ability, they will show similar results in the ability to describe data given in various curves, whether they are in grade 8 or grade 9.

(2) After further investigation into the indicative items of the R2 group we find the following:



Graph 1. The response patterns for students of differing ability

2a. Among the samples of this longitudinal study, there are 24 out of 114(grade 8) and 19 out of 109 (grade 9) students who accomplished the selected items (C24, C29, C30) in this year's test; within these groups there are 19 out of 24 (grade 8) and 11 out of 19 (grade 9) students who had also succeeded in the previous year's test (B26, B44). Yet, comparing those who succeeded only in this year's test with those who succeeded in the two different year's tests (i.e., succeeded on the entire 5 items, B26, B44, C24, C29, C30) shows almost the same responses in the X23 cluster and on the total test, with a slight difference in several individual items such as B25 and C21 (although these two items showed facility all above 70%, in spite of the failure on the previous year's test). In other words, whether or not the students were successful in describing data and in describing the relationships between curves the previous year, they could handle various kinds of descriptive data from given curves including the problem of describing various relationships between curves well (facility on X23 and on the entire test are all in the range of 80% ± 5%) and displayed quite similar response patterns for the ability to describe data(except for a few individual items), as long as they succeeded on the indicative items C24, C29 and C30 this year, regardless of their grade (whether in grade 8 or grade 9). So the items C24, C29 and C30 of this year did serve as indicators of the X23 cluster. Once they can do problems in C24, C29 and C30, they are be able to do the problems in the X23 cluster with about 80% success, even if they are now in only grade 8.

2b. For those grade 8 students who succeeded on the 5 items (i.e., those who succeeded on problems B26 and B44 last year when they were in grade 7, and also succeeded on the problems C24, C29 and C30 this year), their ability to interpret data is above those who could succeed only in grade 9, since the former can handle almost every item perfectly in the description of data over these two years (except in C21 of this year, where their success is also as high as 80%).

2c. For those who failed in both the succeeding two years (in B26 and B44 last year, and C24, C29 and C30 this year) the ability to interpret data was shown to be far below(success on the entire test and on X23 are below 18%) the students mentioned before, in spite of grade difference. Their mean score on achievement tests in math and physical science also were far below those of the successful groups. So the well-selected items which could indicate a certain ability(in this case, the ability to describe the relationship between curves) might consistently reflect their responses

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in various ways.

(B) The results of the pilot study for item construction using SOLO Taxonomy are as follows: The reliability of the test shown by the data of the Kr20 coefficient and the internal consistency shown by the correlations are all satisfactory. (see appendix II)

Table 4. The reliability coefficients of different grades.

	MATH	SCHOOL MEAN	TEST MEAN	TEST (%)	Kr20
7 GRADE(502)	75.28	72.11	12.59	.31	0.8380
8 GRADE(507)	67.16	69.29	15.02	.38	0.8681
9 GRADE(407)	57.95	63.91	18.44	.46	0.8830

(1) For students of this pilot test school, their mean IQ scores are almost the same regardless of their grade, as shown in Graph 2; yet the means of the total scores on this test, the R2 cluster, the Q3, and the rest of the questions, are quite different, with significant differences between grades, as shown in the appendix III). This implies that the questions consturcted according to SOLO Taxonomy could be used to differentiate ability between different grades, though their average IQ is almost the same.

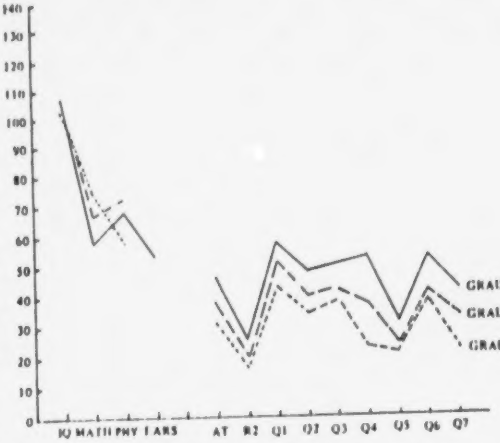
(2) After further investigation into items 14, 15, 16 and 17 in Q3 corresponding to unistructural, relational multistructural and extended abstract catagories, respectively, of SOLO Taxonomy, the responses for those items shown in table 5 could lead to the following inferences:

2a. For those who failed on item 14, the probability of answering correctly the rest of the items in Q3 is low, regardless of grade differences. So item 14 is the simplest, in agreement with SOLO Taxonomy.

2b. For those could not succeed on item 17, the probability of answering item 14 correctly is below 29.9%, while that of answering item 15 or/and 16 correctly is below 11%. So item 17, surprisingly enough, is more difficult than item 14.

2c. Item 15 is the most difficult one, since for even those who failed on item 15, the probability of answering the rest of the items correctly still exceeds 67.8%.

2d. Since, for those who failed on item 16 the probability of answering item 15 is only 7.7%, while the probability of answering the rest of the items is 19.3%, when they failed on item 16.



Graph 2. The mean score of different clusters in the pilot test with their average IQ.

So the order of difficulty of the items, as analyzed from the responses of the students on each item, is not quite consistent with that predicted by SOLO Taxonomy. Item 17 shall be reviewed in a future study.

(3) In order to further investigate the possibility of differentiating the ability of students with the help of Q3, the responses of students were grouped into 5 groups: (Graph 3)

G1: those who correctly answered all the items in Q3.
G2: those who correctly answered in items 15 and 16 only in Q3.
G3: those who correctly answered in items 14 and 16 only in Q3.
G4: those who correctly answered item 14 only in Q3.
G5: those who failed all items in Q3.

G2 stands for those who could point out common features in several curves and describe the relationships satisfactorily in Q3. G3 stands for those who could read off data and point out common features in several cuves given in Q3. G4 stands for those who could read off data only. In the data shown above, we can find the following:

3a. G1 and G2 students who have almost the same IQ(their mean is the highest) and differ only slightly in their school achievement tests (Math, Physics, etc), responded similarly in this pilot test. The response patterns of these two groups are fairly close, which could imply that, once the students could handle item 15 and item 16, they could nearly handle Q3 problems and could also reflect their ability to answer the

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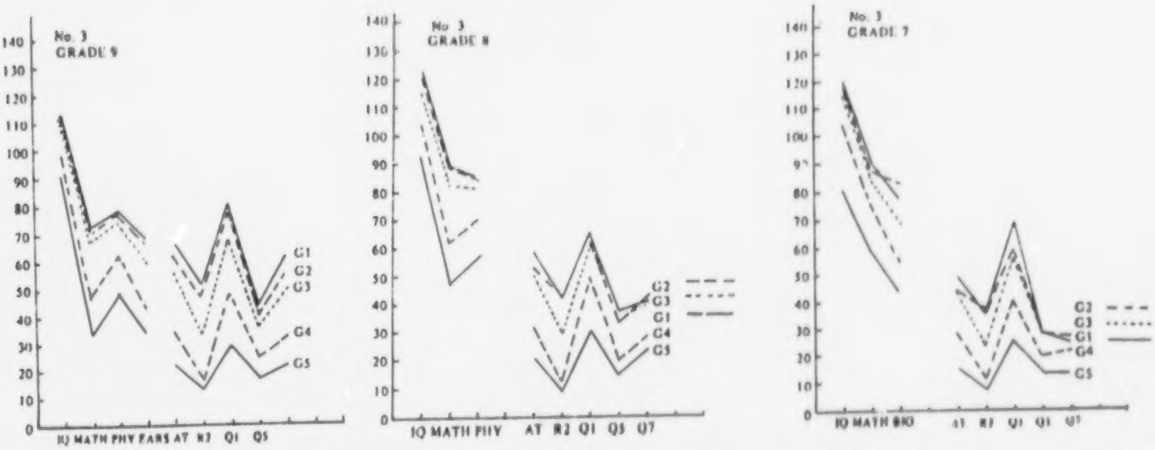
Table 5. The response patterns on different items in question 3

A14	A15	A16	A17	GRADE 9		GRADE 8		GRADE 7	
				Frequency	%	Frequency	%	Frequency	%
•	•	•	•	44	10.8	37	7.3	24	4.8
•	•	•	-	9	2.2	12	2.4	11	2.2
•	•	-	•	23	5.7	20	3.9	23	4.6
•	•	-	-	4	1.0	14	2.8	16	3.2
•	-	•	•	57	14.0	66	13.0	51	10.2
•	-	•	-	16	3.9	20	3.9	24	4.8
•	-	-	•	105	25.8	80	15.8	82	16.3
•	-	-	-	82	20.1	133	26.2	150	29.9
-	•	•	•	7	1.7	3	.6	4	.8
-	•	•	-	0	0.0	3	.6	2	.4
-	•	-	•	2	.5	5	1.0	2	.4
-	•	-	-	2	.5	0	0.0	1	.2
-	-	•	•	5	1.2	7	1.4	3	.6
-	-	•	-	1	.2	1	.2	1	.2
-	-	-	•	10	2.5	20	3.9	15	3.0
-	-	-	-	40	9.8	86	17.0	93	18.5
				---	---	---	----	---	----
				407	100.0	507	100.0	502	100.0

• : indicates correct response



Graph 3. The response patterns of groups of differing levels of alility

different questions in a similar manner.

3b. G3 students show little difference in their average IQ with G1 and G2, but differ more greatly in their school achievement tests. They show a greater degree of difference in their responses among the various clusters of problems in this pilot test, with a lower mean score. So their ability appears to be a little bit lower than that of G1 or G2.

3c. G4 students display much lower ability as compared with G1, G2 and G3 in every respect as shown above, regardless of their grade differences.

3d. G5 students are apparently the least able students in every respect as shown above. This is an alternative attempt used by the author to differentiate

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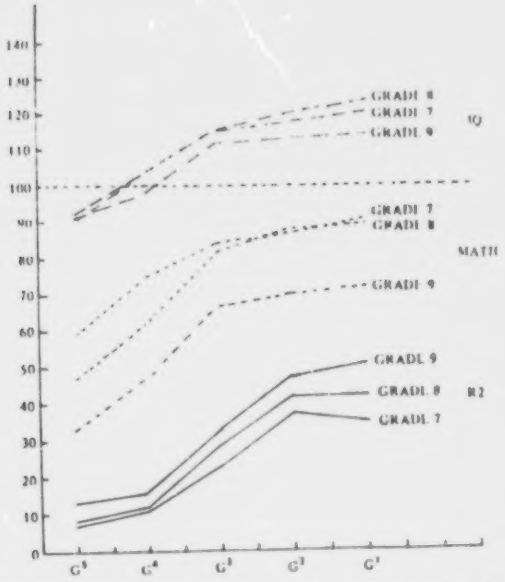
the abilities among students when a single item is not adequately indicative, as predicted by SOLO Taxonomy.

(4) The response patterns of different groups of students shown in Graph 5 manifested quite well their levels of ability in their mean IQs, in their mathematics achievement tests, and in their ability to describe the relationship between curves given in different questions clustered as R2 of this pilot test.



Graph 4. The responses of different ability groups in R2, in math and their mean IQs.

4a. The R2 cluster consists of 5 items(7, 15, 23, 29, and 36) arranged respectively, in different questions in this pilot test; the average scores of each item and the R2 cluster for different grades are shown in Table 6. Comparing the average R2 score of each grade with the response pattern on R2 in each grade, we can find that the problems requiring students to describe satisfactorily the relationship between given curves are not easy at all for most students, whether they are in grade 7 or 9, yet there is a slight increase in average score with respect to their grades. However, the deep slope in the response patterns for the R2 cluster in the region of G3 in each grade might imply that the ability of the G3 student group to read off data and point out common features of several curves is critical in the description of relationships. For those in the G1 and G2 groups, who could point out the common features of various curves and complete a satisfactory description of the relationship between curves given in question 3, the response pattern might suggest that those who have ability similar to those in G1 or G2 would better handle the R2 cluster problems than those who could only read off data and point out common features in question 3.

Table 6. The average success on problems in the R2 cluster.

	A36	A7	A15	A29	A23	R2
7 GRADE(502)	.03	.10	.17	.18	.31	.16
8 GRADE(507)	.07	.17	.19	.19	.37	.20
9 GRADE(407)	.11	.17	.22	.32	.41	.25

4b. Although the G2 or G1 groups differ significantly from the rest of the groups in describing relationships (as clustered in R2), the facility of G2 or G1 in the R2 cluster is only about .4. So the ability of G2 or G1 in question 3 is not indicative enough to define ability to describe relationships between curves given in various problems. I.e., one item in a single question constructed according to SOLO Taxonomy might not be sufficient to serve as an indicator of ability in this respect, even though it shows better ability to differentiate ability to handle R2 cluster problems.

Conclusions

1. In order to develop an instrument for testing ability in a certain area, such as in the interpretation of data, the indicative items with which the test is constructed and from which the ability of students is assumed to be reflected in test performance, should be searched for, either through top-down analysis based on theory concerning the ability of students, or through bottom-up analysis based on consistent performance in test results. Both approaches were adopted in this study to ensure the validity of test construction.

2. Analysis based on consistent performance of the students is essential to confirmation that the test items are indicative enough of student's ability, especially for those items designed to look at the various aspects of ability concerned, (e.g., in the description of relationships between various curves). The results obtained from 3 years cross-sectional and longitudinal studies are promising; the indicative items thus found displayed satisfactory consistency in the performance of students being traced. This also

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implies that this approach could work in the selection of indicative items. However, it is time consuming, particularly in the domain of interpreting data concerning higher levels of ability.

3. SOLO Taxonomy, which classifies the performance of students into several levels based on cognitive literature, has merits in the design of question structure for the analysis of ability level, especially in those open-ended questions requiring the integration of inter-related information given in curves. With the items of question 3 in the pilot test thus designed, the results of the test when their responses are analysed show that there is a little inconsistency in the order of difficulty level assumed to reflect corresponding ability. Instead of using a single item to differentiate the ability of students, an alternative attempt was made to group the students into 5 ability levels according to their various responses in question 3. The results show that this could help to differentiate the students either for their IQ mean or their achievement mean score in mathematics or in the R2 cluster (items of different questions all related to the description of relationships between various curves). However, facility in the R2 cluster shown by the upper level groups catagorized from question 3 also suggests that the items in a single question constructed according to SOLO taxonomy might not be sufficient to serve as indicators. More effort has to be made to investigate the responses to other questions, and further analysis, including cross examination of the responses to various questions, has to be done, and , perhaps, modifications have to be made before SOLO Taxonomy can be fully adopted to design indicative items successfully. Yet this approach might provide a short-cut method for test construction.

4. If performance on a test is to reflect some postulated attributes of students, the test has to be constructed in such a way that ther are adequate test items all indicative of the different levels of ability to be measured. Hence, the "spectra" of the responses of students of different levels of ability must be found. The more complete the "spectra lines" are, the greater accuracy in the description of ability in the domain concerned can be derived. When considering the constraint of time for a test and the limited number of items on a test, the indicative items reflecting different levels of ability must be searched for until the ability of students in a certain domain can be well defined by the responses shown consistently for those items. Efforts as described in this study might provide an avenue for further exploration in the development of tools for testing process skills.

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References

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning: The SOLO Taxonomy*. New York: Academic.

Biggs J. B. & Collis K. F. (1982). *Evaluating the quality of learning: The SOLO Taxonomy* (Structure of the observed learning outcome).

Burn, J. C., Okey, J. R. & Wise, K. C. (1985). Development of an integrated process skill test: TIPS II, *Journal of Research in Science Teaching, 22* (2),169-177.

Burns, S. F. (1972). The development of a test to measure performance of elementary education majors on the American Association for the advancement of science's integrated process skills of science, Diss. Abstr. Int., 33, 2783-A (Doctoral dissertation, The University of Connecticut, 1972) (University Microfilms No. 72-32, P.205).

CSMS (Concepts in Secondary Mathematics and Science 1980) *Monograph reports on the mathematic component of the research Programme*. Centre for Science Education, Chelsea College, University of London.

Dillahaw, F. F. & Okey, J. F. (1980). Test of the integrated science prcoess skill for secondary science students. *Science Education, 64* (5). 601-608.

Gagne, R. M. and Paradise, N. E. (1961) *Abilities and learning sets in knowledge acquisition*. Psychological Monographs: General and Applied 75, Whole No.518.

Lord, F. M. (1968). An analysis of the verbal scholastic aptitude test using Birnbaum's three-parameter logistic model. *Educational and Psychological measurement, 28*, 989-1020.

------(1974). *Practical methods for redesigning a homogeneous test, also for designing a multi-level test*. Research Bulletin 74-30. Princetion, NJ: Educational Testing Service.

------(1980a). *Application of item response theory to practical testing problems*. Hillsdale, N.J.: Erlbaum.

Ludeman, R. R. (1975). *Development of the Science Processes Test (TSPT)*. Diss. Abstr. Int., 36, 203-A, (Doctoral dissertation, Michigan State University,1974) (University Microfilms No. 75-14, p. 738).

Mao Song-Ling (1987). The study of instrument deve-lopment for the measurements of data processing and interpretation. *Proceeding of Science Education Conference*, N.S.C., Taiwan.

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R.O.C., 321-350.

------(1988). The analysis of ability levels of grade 7&9 year students in data processing and interpreting. *Proceeding of Science Education Conference*, N.S.C., Taiwan, R.O.C., 241-278.

------(1989). The growth study on the ability of plotting, and interpretating information from data in 7-9 grade. *Proceeding of Science Education Conference*, N.S.C., Taiwan, R.O.C., 373-406.

Mayer, V. J. & Richmond, J. M. (1982). An overview of assessment instruments in science. *Science Education*, *6*, 49-66.

Moled *at al*. (1975). The development of criterion-validated test items for four integrated science processes. *Journal of Research in Science Teaching*, *12*, 415-421.

Molitor, L. L. & George, K. D. (1976). Development of a test of science process skills. *Journal of Research in Science Teaching*, *12*, 415-421.

Rasch, G. (1960). *Probalistic models for some intelligence and attainment tests, Copenhagel*. Danish Institute for Educational Research.

Riley, J. W. (1972). *The development and use of a group process test for selected processes of the science curriculum improvement study*. Diss. Abstr. Int., 33, 6200A-6201A (Doctoral dissertation, Michigan State University, 1972) (University Microfilms No. 73-12, p.807).

Tannenbaum, R. S. (1968). *The development of the test of science processes*. Diss. Abstr. Int., 29,2159-A (Doctoral dissertation., Columbia Unversity, 1986) (University Microfilms No. 69-677).

Tobin, K. G. & Capie, W. (1982). Development and validation of a group test of integrated science processes. *Journal of Research in Science Teaching*, *19*, 133-141.

Wright B. D., *Sample-free test calibration and person measurement*. Proceedings of the 1967 Invitational Conference on Testing Problems, Princeton, N.J. Educational Testing Service, 1986.

Wright, B. D. & Stone, M. H. (1979), *Best test design, Rasch measurement*. Chicago: The University of Chicago, Mesa Press.

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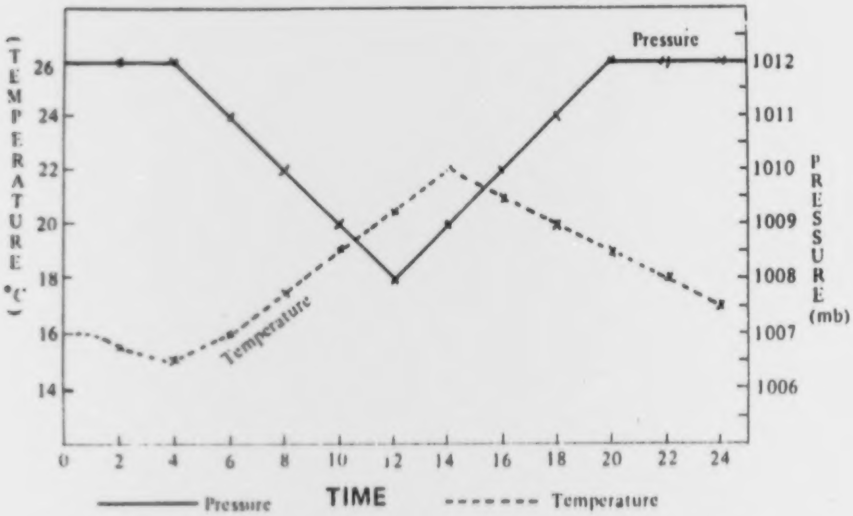
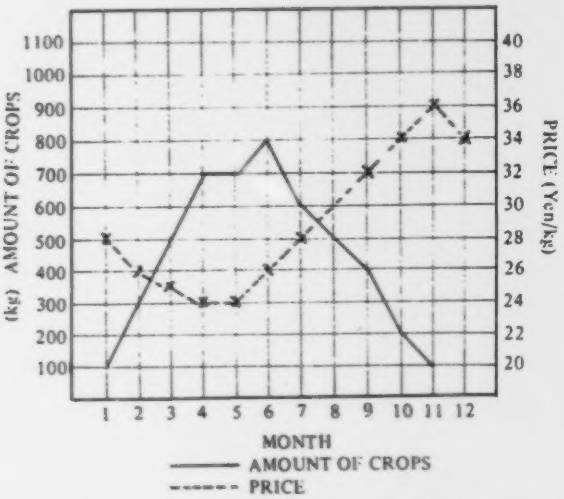
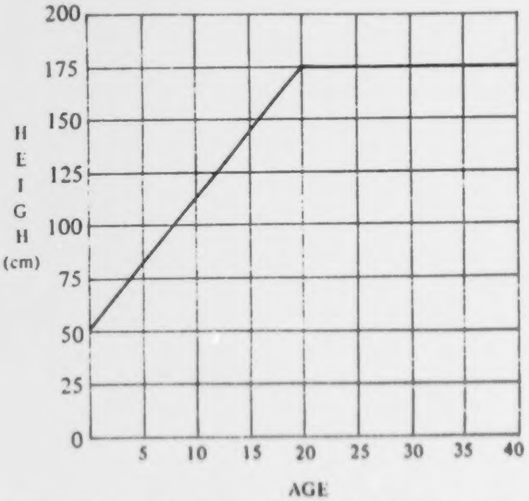
Appendix I.



C24: Please describe the relationship between temperature and pressure with respect to the change of time between 0 to 12 o'clock.



C29: As a whole what is the relationship between the amount of crop production and price with respect to different month.



C30: This graph shows the relationship between a boy's height and his age. Please describe this relationship in a few lines.

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Appendix II. The correlations of the R2 cluster between groups and the IQ, the total score(AT), etc.

GRADE 9 :

Correlations :	A14	A15	A16	A17	Q3	R2
A14	1.0000	.0405	.1120	.2169••	.4209••	.0747
A15	.0405	1.0000	.4044••	.2412••	.5840••	.5797••
A16	.1120	.4044••	1.0000	.2580••	.6452••	.2879••
A17	.2169••	.2412••	.2580••	1.0000	.7783••	.2060••
Q3	.4209••	.5840••	.6452••	.7783••	1.0000	.4363••
R2	.0747	.5797••	.2879••	.2060••	.4363••	1.0000

N of cases : 349 Significance : •-.01 ••-.001

" . " is printed if a coefficient cannot be computed.

GRADE 8 :

Correlations :	A14	A15	A16	A17	Q3	R2
A14	1.0000	.1472••	.2397••	.2177••	.5152••	.1992••
A15	.1472••	1.0000	.3053••	.2198••	.5321••	.5147••
A16	.2397••	.3053••	1.0000	.3857••	.6946••	.3315••
A17	.2177••	.2198••	.3857••	1.0000	.8097••	.2941••
Q3	.5152••	.5321••	.6946••	.8097••	1.0000	.4703••
R2	.1992••	.5147••	.3315••	.2941••	.4703••	1.0000

N of cases : 473 Significance : •-.01 ••-.001

" . " is printed if a coefficient cannot be computed.

GRADE 7 :

Correlations :	A14	A15	A16	A17	Q3	R2
A14	1.0000	.1321•	.1954••	.2251••	.5185••	.1979••
A15	.1321•	1.0000	.2625••	.2138••	.5166••	.4997••
A16	.1954••	.2625••	1.0000	.3152••	.6326••	.2627••
A17	.2251••	.2138••	.3152••	1.0000	.8104••	.2262••
Q3	.5185••	.5166••	.6326••	.8104••	1.0000	.4076••
R2	.1979••	.4997••	.2627••	.2262••	.4076••	1.0000

N of cases : 484 Significance : •-.01 ••-.001

" . " is printed if a coefficient cannot be computed.

GRADE 9 :

Correlations :	IQ	MATH	PHY	EARS	MEAN	AT
A14	.2188••	.2454••	.2117••	.2000••	.2457••	.3201••
A15	.2336••	.2537••	.2189••	.3160••	.3250••	.4351••
A16	.2487••	.2561••	.2365••	.2651••	.3264••	.4046••
A17	.3233••	.3176••	.2935••	.2921••	.3412••	.5081••
Q3	.4264••	.4238••	.3813••	.4321••	.4906••	.6764••
R2	.3761••	.3025••	.2945••	.4793••	.4739••	.6349••

N of cases : 349 Significance : •-.01 ••-.001

" . " is printed if a coefficient cannot be computed.

GRADE 8 :

Correlations :	IQ	MATH	PHY	MEAN	AT
A14	.3269••	.3250••	.3474••	.3370••	.4149••
A15	.2636••	.2793••	.2243••	.3034••	.3188••
A16	.2974••	.3375••	.3246••	.3265••	.4749••
A17	.3300••	.3062••	.2990••	.3221••	.5556••
Q3	.4564••	.4545••	.4360••	.4689••	.6850••
R2	.4120••	.4406••	.4223••	.4561••	.5863••

N of cases : 472 Significance : •-.01 ••-.001

" . " is printed if a coefficient cannot be computed.

GRADE 7 :

Correlations :	IQ	MATH	PHY	MEAN	AT
A14	.3688••	.3024••	.3167••	.3598••	.4673••
A15	.2040••	.2114••	.2462••	.2351••	.2846••
A16	.3237••	.2619••	.3124••	.3231••	.4206••
A17	.2787••	.2423••	.2966••	.3193••	.5052••
Q3	.4312••	.3878••	.4442••	.4704••	.6543••
R2	.3854••	.3553••	.3757••	.4102••	.5729••

N of cases : 481 Significance : •-.01 ••-.001

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Appendix III. The t-test of different clusters and the test scores

T value 2-tail prob.	Take reading from curve	Select suitable Explanation	Generalization	Giving Reasons	Deriving Common Attributes	Describing Relationship	Test Score
between grade 7-8	-2.94 .003 •	-5.44 .000 •	-5.19 .000 •	-3.74 .000 •	-4.12 .000 •	-3.68 .000 •	-6.41 .000 •
between grade 8-9	-5.23 .000 •	-2.08 .000 •	-6.15 .000 •	-6.16 .000 •	-3.51 .000 •	-3.23 .000 •	-6.64 .000 •
between grade 7-9	-8.10 .000 •	-6.99 .000 •	-10.96 .000 •	-9.57 .000 •	-7.34 .000 •	-6.56 .000 •	-12.55 .000 •
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
between grade 7-8	-4.22 .000 •	-4.35 .000 •	-2.02 .044 •	-5.68 .000 •	-2.94 .003 •	-1.90 .057 •	-8.24 .000 •
between grade 8-9	-2.42 .016 •	-6.27 .000 •	-3.80 .000 •	-4.29 .000 •	-4.24 .000 •	-6.18 .000 •	-4.58 .000 •
between grade 7-9	-6.83 .000 •	-10.49 .000 •	-5.84 .000 •	-9.66 .000 •	-6.99 .000 •	-7.69 .000 •	-11.83 .000 •

•:There is significant difference between grades.

測驗工具發展研究中指標性試題之尋求方法

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摘 要

在測試時間與題數之限制之下要發展出一種可適合我國需要的科學過程技能標準化測驗工具，則該工具中之每一測驗項目必須均具有指標性，以便使不同受試者之能力可充分反應表現出來；同時使同一種能力水準之受試者對這些指標性試題均能呈現幾乎近似之反應型態。

由三年來深入探討如何自行發展〞解釋資料評量工具〞之研究經驗，本文即在回顧並指出，除了傳統性的以專家觀點主觀選定代表性試題之方式外，尚有兩種應加以運用，才能使試題更具有指標性：即(A)由長期橫斷性及縱貫性之研究分析來驗證所選試題是否具有指標性；(B)採用有關認知理論所引申出來之學生反應層次模式（SOLO）來設計試題並加以對比分析，以確定其指標性之程度。

以上兩種方法經過測試分析結果顯示受試者針前者所選指標性試題之反應型式甚爲一致；而對後者發現雖然試題已照理論模式加以架構，學生能力亦可顯示其差異性，但若要純以單一之試題來深入分析學生是否確定具有某項能力，則仍嫌不足，有待進一步之改進或其它方法之輔助運用。

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A Study of the Professional Competencies of Vocational Industrial Teachers

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ABSTRACT

Education is a basic foundation stone of a country. The fulfillment of our educational ideas depends upon well-educated teachers. The quality of these teachers will influence the quality of educational outcomes. Therefore, the purpose of this study was to investigate the competencies required for vocational industrial teachers in Taiwan. Specifically, four items were pursued: (1). To identify qualified teachers' competencies; (2). To determine the credit number of technical courses for qualified industrial teachers; (3). To determine degree and the length of work experience of qualified industrial teachers; (4). To develop recommendations for designing industrial teacher curriculum and in-service training programes, and select professional teachers.

The questionaire used in this research was designed according to the related literature. It contained competencies in eleven categories: professional capacity, curriculum development, instructional preparation, instructional execution, instructional evaluation, instructional management, guidance, school community relations, cooperative education, school administration, and professional role. A total of 1368 questionaires were sent to the sample to collect necessary data, and 1,002 were returned.

The major findings were: (1). A competent teacher should have all the competencies in the questionnaire; (2). Twenty to thirty credits of technical courses should be taken by a competent industrial teacher; (3). Graduates from either industrial education or engineering programs should be competent industrial teachers; (4). One to two years of work experience in industry should be required for competent industrial teachers. From the above findings, basic requirements for qualified industrial teachers can be reached for the use of teacher education, in-service training programs and teacher selection.

Recommendations include: (1). Vocational industrial teachers should have the identified competencies in order to function well on their jobs. (2). A bachelors' degree in engineering or industrial education, twenty to thirty credits of technical course and one to two years of work experience should be considered to be the minimum requirements for qualified industrial teachers. Engineering majors need to be trained in the identified competency areas. (3). A series of professional courses with an aim to perpetuate required competencies should be recognized as core courses for industrial teacher education curriculum and in-service training programs.

Key words: industrial education, vocational education, teacher education competencies, teacher certification, in-service training, curriculum

I. Introduction

Vocational industrial education has played an important role in providing skilled workers for industrial sectors in Taiwan during the past four decades. In

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order to keep pace with the prospering economy and changing technology, the government set up a three-phase industrial education reform plan to improve teaching effectiveness and shop equipment and facilities, and to accommodate more industrial high school students. In 1987, the ratio of the number of reqular high school students to vocational major students was 3 to 7. Among the vocational students, the percentage of vocational industrial students was 48.50% (Yang, 1988). This percentage has stablized in recent years. Because of the growing vocational student population and obvious shortage of qualified industrial teachers in the private vocational industrial schools in Taiwan, this is an appropriate time to review methods of industrial teacher training, appointment, and in-service training.

The quality of vocational industrial education depends on the quality of industrial teachers. From a macro point of view, to provide well-educated skilled workers for industry, the most effective way is to produce quality industrial teachers. From the student's point of view, only good teachers can produce quality students. Therefore, some standards should be set for teacher education, appointment and in-service training to produce these quality industrial teachers. Qualified industrial teachers' competencies can fit the function of forming a sound base for these standards.

Role expectations of industrial teachers is another concern of society. In order to conform with the role expectations, industrial teachers need to know exactly what tasks they should perform and competencies they should have as teachers. It is necessary to identify a list of successful industrial teacher competencies to meet this prupose (Wu, 1984).

Competency-based teacher education necessitates the identification and verification of competencies as well. According to the literature related to teacher education, teachers' competencies have been classified into three stages. Beginning teacher competencies are those competencies which meet the basic requirments for beginning teachers. Experienced teacher competencies are those which are held by teachers with theoretical bachground and teaching experience. At the last stage, master teachers possess educational, administration and leadership abilities in addition to the experienced teacher competencies (Kang, 1980).

It was the intent of this study to identify the competencies held occupied by competent industrial teachers. Specifically, the purposes of this study were:

1. to identify competent teachers' competencies.
2. to determine the credit number of technical courses for competent industrial teachers.
3. to determine the degree and the length of work experience of competent industrial teachers.
4. to derive recommendations for designing industrial teacher curriculum and in-service training programs, and to write guidelines for selecting professional teachers.

II. Review of Literature

Since the movement of competency-teacher education began, researchers have studied teacher competencies in more scientific ways. The movement was based on changes in educational theories, the results of educational psychology research, shifts in the social environment, and the influence of scientific management. Among the scientific ways of classifying teachers' competencies, Brown and Okey (1971) indicated that teacher competency should be devided into three stages. First, beginning teachers should possess minimum competencies to ensure the performance of basic teaching tasks in schools. At the second stage, experienced teachers need to build up enough academic knowledge and work experience. At the third stage, master teachers should have the ability to teach successfully, to conduct research independently and to assume administration work.

Competencies usually have been associated with one's profession. In order to play one's teaching professional role well, a person needs to possess necessary cognitive, affective and psychomotor characteristics, and perform required tasks at a mastery level (Moss, 1971). There have been some studies related to teacher competencies completed in Taiwan (Kang, 1980; Lin, 1978; Taiwan Provincial Teachers' College, 1975; Wu, 1984). The results of a study analyzing high school teacher competencies showed that high school teachers should have the basic competencies in the aspects of educational idiology, general knowledge, teaching ability, morality, educational knowledge, social relationships, and health and appearance (Taiwan Provincial Kaoshiung Teachers' College, 1975). Sixty eight competencies were found.

The Taiwan In-Service Training Center for Elementary School Teachers reported that elementary teachers were required to perform many roles which were related to various areas of responibilities, including learning assistance, classroom management, student advising, and career guidance. There were four hundred and seventy eighy competencies found. Lin (1978) also conducted research on special education research teacher competencies, in which sixty professional competencies were identified.

In 1960, the U.S. Department of Health, Education and Welfare (Walsh, 1960) studied basiccompetencies needed by vocational industrial teachers. They concluded that good vocational industrial teachers should understand public education, understand students and the learning environment, select, develop and use instructional materials, apply pedagogical strategy, develop useful curriculum, organize and manage the teaching place, and conduct public relations. The National Center for Research in Vocational Education (1978) at Ohio State University suggested ten major areas of vocational industrial teacher competencies. They were program planning, development and evaluation, planning of instruction, execution of instruction, evaluation of insruction, management of instruction, guidance, school-community relations, student vocational organizations, coordination, and professional role and development.

Other studies directly related to vocational industrial teacher competencies revealed more comprehensive views on teacher competencies. That is, although teaching is a major function of a vocational industrial teacher's role, there are still other functions which are instrumental to the fulfillment of the teacheis role. (Chang, 1978; Kang, 1980; Wu, 1984). For example, Kang (1980) maintained that a successful industrial teacher should have seven major competencies: professional competency in industrial education, human relations competency, program planning and evaluation competency, instructional competency, competency of technical knowledge and skills, shop and classroom management competency, and teaching evaluation competency.

III. Research Design and Data Analysis

The impact of educational, psychological and social changes, and the scientific management movement on the vocational industrial teacher's role and competencies have been evident in the related literature. From the literature, a list of vocational industrial teacher competencies was found for the identification of necessary competencies, which were then selected by industrial teachers and scholars.

Then, the identified competencies were grouped into many units to make up the content of individual courses for preparing teacher education curriculum and in-service training programs. Also, from these identified competencies could be derived industrial teachers' standards for teacher selection and appointment purposes (See Fig. 1).

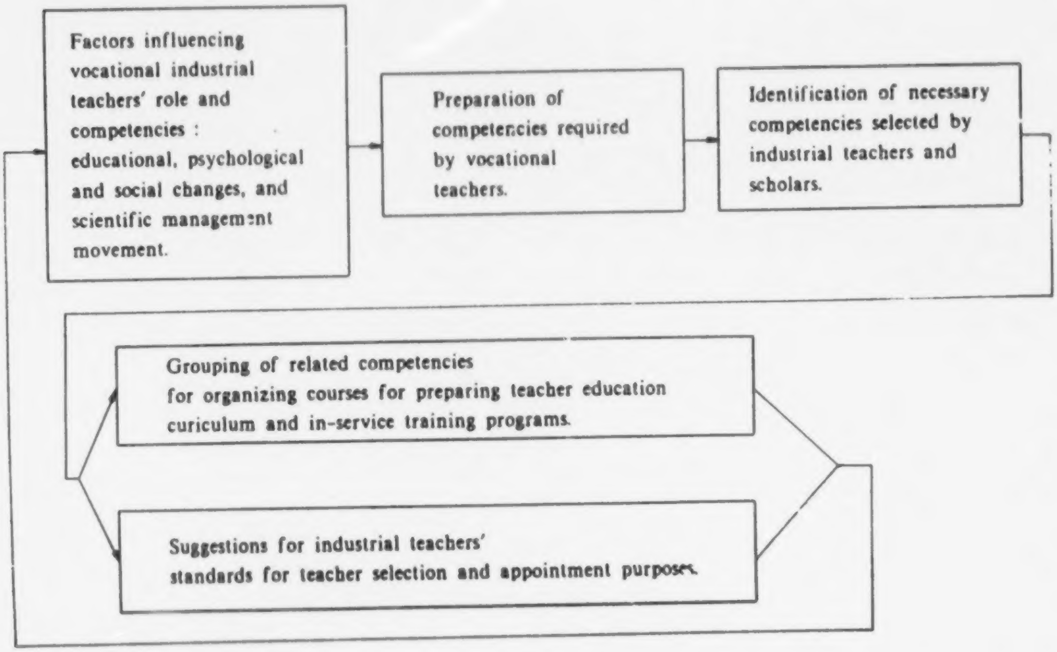
Factors influencing vocational industrial teachers' role and competencies : educational, psychological and social changes, and scientific management movement.
Preparation of competencies required by vocational teachers.
Identification of necessary competencies selected by industrial teachers and scholars.
Grouping of related competencies for organizing courses for preparing teacher education curiculum and in-service training programs.
Suggestions for industrial teachers' standards for teacher selection and appointment purposes.

Figure 1. Theoretical Framework of the Research

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In this study, the questionnaire designed by the researchers was the result of reviewing the related literature. It was especially influenced by Kang's ideal industrial teacher competencies (1980), vocational teacher competencies developed by the Ohio Center for Vocation Education (Cotrell, 1971), and Wu's vocational industrial teachers' functions (1984). These competencies were classified into eleven major categories: (1) Professional Capacity; (2) Curriculum Development; (3) Instructional Preparation; (4) Instructional Execution; (5) Instructional Evaluation; (6) Instructional Management; (7) Guidance; (8) School Community Relations; (9) Cooperative Education; (10) School Administration; and (11) Professional Role.

The population used for this study was composed of teachers from 162 schools including vocational industrial schools, agricultural and industrial schools, business and industrial schools, home economics and industrial schools, comprehensive schools, and the faculty of the Department of Industrial Education at three normal universities. The sample involved 70 university faculty members and 1,298 industrial high schools teachers.

Data were collected from the sample. A total of 1,368 questionnaires were sent to the respondents, and 1,002 questionnaires were returned, for which a return rate of 73.25% was obtained. Among the 1,002 returned questionnaires, only 855 were considered to be usable.

The data were coded and analyzed by applying statistical methods including mean, standard deviation, Chi-square tests, and t-tests. The respondents were asked (1) to check the appropriate level of importance of each competency for beginning teachers, experienced teachers and master teachers, and (2) to check the appropriate level of possession of each competency which best represented the respondent's current status. Each response to an indicated questionnaire item was coded into one of the 5 scales, of which 5 indicated "extremely needed", 4 indicated "needed", 3 indicated "undecided", 2 indicated "not needed", and 1 indicated "extremely not needed".

IV. Findings

The average scores for all competency items reached at least 3.0, indicating that industrial teachers should have all the competencies shown in the questionnaire. These competencies were:

A. Professional Capacity:

1. Understand the differences between vocational education and general education.
2. Understand the characteristics of vocational industrial education.
3. Understand the relationship between human development and national economic development.
4. Understand the relationship between occupations and education.
5. Understand the history and development of industrial education.
6. Understand the trend and future perspectives of industrial education.
7. Understand industrial education policies and the related regulations.
8. Understand occupations and their future development.

B. Curriculum Development:

1. Conduct an occupational analysis.
2. Prepare curriculum objectives in industrial education.
3. Develop teacher-made instructional materials.
4. Conduct curriculum evaluation.

C. Instructional Preparation:

1. Determine needs and interests of students.
2. Conduct instructional design.
3. Develop student performance objectives.
4. Plan a unit of instruction.
5. Write a lesson plan.
6. Write instruction materials.
7. Prepare teaching aids.

D. Instructional Execution:

1. Master technical knowledge of courses being taught.
2. Familiarize technical skills of courses being taught.
3. Present a lesson.
4. Motivate students to learn.
5. Employ oral communication techniques.
6. Demonstrate technical skills.
7. Utilize proper instructional materials and teaching methods.
8. Utilize teaching aids.
9. Direct shop experience.
10. Diagnose and alleviate students' learning disabilities.
11. Conduct field trips.

E. Instructional Evaluation:

1. Establish criteria for student performance.
2. Write objective questions.
3. Write subjective questions.

4. Assess student cognitive performance.
5. Assess student psychomotor performance.
6. Assess student affective performance.
7. Determine student achievement.
8. Conduct item analysis.
9. Determine student grades.

F. Instructional Management:

1. Plan instructional resource needs.
2. Manage and maintain vocational-industrial laboratory.
3. Prepare rules for equipment and material management.
4. Maintain a filing system.
5. Plan shop space.
6. Evaluate and improve shop layout.
7. Manage matters regarding shop safety and hygiene.
8. Manage shop accidents.
9. Assist students in developing self-discipline.

G. Guidance:

1. Understand student aptitude and ability.
2. Gather students' personal data.
3. Be familiar with talk techniques.
4. Assist students in understanding themselves.
5. Provide information on education and career opportunities.
6. Assist students in applying for employment or further education.
7. Conduct a follow-up survey.
8. Participate in student activities.
9. Interpret the results of psychological tests.

H. School-Community Relations:

1. Cooperate with guidance organizations in employment.
2. Maintain communication among students teachers and administrators.
3. Liaison with community members, students' parents and employers.
4. Cooperate with others.
5. Promote public relations through community activities.
6. Provide displays and brochures to inform students, parents and the community about program planning and objectives.
7. Prepare news releases for public media.

I. Cooperative Education:

1. Participate in studies of local industry.
2. Maintain communication between school and industry.
3. Design training programs for students and industry.
4. Select appropriate factories to cooperate with schools.
5. Coordinate among students, parents and factories.
6. Prepare rules to evaluate cooperative education students.

J. School Administration:

1. Provide student advising and guidance services.
2. Assist schools in administration.
3. Assist student clubs as advisors.

K. Professional Role:

1. Develop professional knowledge.
2. Conduct vocational industrial studies.
3. Write research reports.
4. Direct or participate in research.
5. Conduct studies to improve teaching methods.
6. Conduct stadies to improve evaluation techniques.

From the results of t-tests to compare the mean scores of each competency required for three types of industrial teachers and the mean scores of the competencies possessed by three types of industrial teachers, respectively, it was apparent that industrial teachers scored lower on competencies than expected, meaning that beginning teachers, experienced teachers, and master teachers had less knowledge and fewer skills than they expected themselves to have.

Credit Number of Technical Courses for Competent Industrial Teachers

Beginning teachers and experienced teachers tended to agree on twenty to thirty credits of technical courses for competent industrial teachers while master teachers and scholars tended to agree on forty credits.

Degree and Length of Work Experience of Competent Industrial Teachers

Most of the respondents agreed that an industrial teacher should have a bachelor's degree earned from an engineering department of a college and university or from an industrial education department of an educational college or university. Female teachers and teachers who graduated from engineering programs favored graduates with engineering background as competent teachers. On the other hand, male teachers

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and teachers who graduated form industrial education programs and graduate institutes favored graduates with industrial education background as competent teachers.

Most of the respondents agreed that competent industrial teachers should at least have one to two years of work experience in industry.

Recommendation for Designing Curriculum and In-Service Training Programs and Selecting Professional Teachers

From the above findings, it is evident that a competent industrial teacher (a) should possess all the competencies to the level which is commensurate with respective types of teachers graduated from engineering programs or industrial education programs, (b) needs to have one to two years of work experience, and (c) earn twenty to thirty credits in technical courses.

V. Conclusions and Recommendations

Based on the findings, conclusions are as follows:

1. Vocational industrial teachers should possess competencies in the followins areas: professional capacity, curriculum development, instructional preparation, instructrial execution, instructional evaluation, instructional management, guidance, school community relations, cooperative education, school administration, and professional role.

2. Competent industrial teachers need to finish twenty to thirty credits of technical courses to be qualified.

3. Competent industrial teachers need to have a bachelor's degree earned from either an engineering or industrial education program. At least one to two years of work experience in industry is needed as well.

The following recommendation are drawn fron the findings and conclusions.

1. The thing most essential to be a competent industrial teacher is to possess the competencies identified in this study. Thus, a list of professional courses are suggested by combining related competencies. These courses are: Introduction to Industrial Education, Curriculum Development and Evaluation in Industrial Education, History of Industrial Education, Design of Instructional Materials, Development and Application of Teaching Aids, Industrial Pedagogy, Instructional Evaluation of Industrial Courses, Teaching Practice, Testing Methods of Technical Skills, Shop Layout and Management, Shop Safety and Hygiene, Guidance, Theory and Practice of Cooperative Education, School Administration, Research and Statistics in Industrial Education, Independent Study, and Technical Courses.

2. Competent industrial teachers should possess the identified competencies, graduate from either an industrial education or engineering program, and earn twenty to thirty credits in professional courses. Graduates from engineering programs need to also receive professional training.

3. Twenty to thirty credits of technical courses should be the minimum requirement for industrial teachers at the beginning level.

4. One to two years of work experience could be arranged through cooperation with industry during the summer.

5. In-service training programs should be designed according to the identified competencies.

References

Brown, L. and Okey, J. (1971). *Identifying and classifying competencies for performance based teachers*. Unpublished paper.

Chang, C. (1978). *A study of competency needs for vocational industrial teachers*. Masters' thesis of the Graduate Institute of Industrial Education at National Taiwan Normal University.

Cotrell, C. (1971). *Model curricula for vocational and technical educators* (Report No. 1). Performance requirements for teachers. Columbus, OH: The Ohio State University, The Center for Vocational and Technical Education.

Kang, T. L. (1980). Ideal industrial teacher competencies. In *Tommorow's teacher education*. Taipei: Youth Publication, Inc.

Lin, M. (1978). *An analysis of special education teacher competencies*. Institute of Education, National Taiwan Normal University, Taipei: National Taiwan Normal University.

Moss, J., Jr. (1971). Assumptions underlying preservice programs for beginning level vocational teachers. In Evans, R. N. & Terry, D. R. (eds.), *Changing the role of vocational teacher education*. Bloomington, IL: Mcknight & Mcknight Publishing Company.

National Center for Research in Vocational Education (1978). *Professional teacher education module series*. Columbus, OH: Ohio State University.

Taiwan Provincial Kaoshiung Teachers' College (1975). *An analysis of educational standards for students of normal universities*. Kaoshiung: Taiwan Provincial Kaoshiung Teachers' College.

Walsh, J. (1960). *Teacher competencies in trade and industrial education*. Washington D.C.: U.S. Government Printing Office.

Wu, T.F. (1984). *A study of vocational high school teacher role and functions with implications on the improvement of teacher education*. Taichung: Shen-Chou Publication Company.

Yang, K. (1988). *Technological and vocational education development plan*. Paper presented at the the 1988 Technological and Vocational Education Conference. Winlin: National Winlin Institute of Technology.

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Vocational Industrial Teachers Competencies

工業職業學校專業教師能力之研究

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摘要

教育乃國家之根本，而教育理想的實現與教育方針的貫徹，則有賴於優秀而健全的教育人員，在教育人員之中又以從事教學工作之教師最爲重要，其素質與能力更直接影響到教育成果的品質，影響我國工業職業教育發展的主要因素有師資、課程、設備、教材等，其中又以師資的良窳最爲重要。本研究之目的乃在探討優良工職教師應具備之能力，所研究之主題包括：

(1)工職工科專業教師應具備的能力及學經歷。

(2)合格工科教師應修的專業科目學分數。

(3)專業教師應具備的實際工作經驗。

(4)根據研究結果作爲工科專業教師課程發展、師資在職訓練及教師甄選辦法之參考。

本研究以七十七學年度現有全國162 所工業職業學校，包括農工職業工科學校、工商職業學校、商工職業學校、工業家事職業學校、綜合中學的教師及師範校院之工教系教師爲母體群。共計1,228位工職教師及40位師範校院工教系教師參與本研究。

本研究之工具係研究者自編之「工業職業學校專業教師能力之研究」調查問卷，其內容包括以下能力項目：工業教育專業能力，課程發展的能力，教學準備的能力，實施教學的能力，教學評量的能力，教學管理的能力，輔導學生的能力，推展公共關係與人際關係的能力，推展建教合作的能力，學校行政能力和專家角色的能力。

對於每一問卷題目填答者需要填答實習教師、經驗教師和精通教師所應具備的能力及填答者具備該能力的情形。統計方法包括平均數，標準差，卡方考驗和t 考驗等。

本研究之主要發現如下：

1. 工職工科專業教師應具備的能力包括：工業教育專業能力（八項），課程發展的能力（四項），教學準備的能力（七項），實施教學的能力（十一項），教學評量的能力（九項），教學管理的能力（九項），輔導學生的能力（九項），推展公共關係與人際關係的能力（七項），推展建教合作的能力（六項），學校，行政能力（三項）和專家角色的能力（六項）。
2. 工科專業教師應具備大學工業教育學系畢業或大學工學院畢業之學歷。
3. 工科專業教師應修學分之專業科目學分數，以２０至３０學分爲宜。理想之學分數爲４０學分以上，可於在職進修時逐步完成。
4. 工業專業教師應具備二年的實際工廠工作經驗。
5. 目前工科專業教師之專業能力一般而言均未達理想狀況。

本研究主要建議如下：

1. 工科教師應具備七十九項專業能力，可於以下科目中涵蓋這些能力：工業教育概論，工業教育課程發展與評鑑，工業科目教學評鑑，教學實習，專業能力測驗方法研究，工場規劃與管理，工場安全與衛生，職業輔導，建教合作的理論與實施，學校行政工業教育研究法與統計，專題研究和專業科目。
2. 工科專業教師宜具有師範大學工業教育系或大學工學院之學歷。大學工學院畢業先應經由教育學分班方式充實其

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應具能力。

3.工科專業教師在校修習之與所任教之專業科目學分數至少有２０至３０學分。

4.師資之任用，進修及甄選均應以此七十九項工科專業教師應具備之能力爲主要依據，以研擬相關辦法。

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Authors should present their materials with the utmost conciseness consistent with clarity. Manuscript must be typed legibly on only one side of each page, on 210 x 280 mm white paper (not "erasable" or onion skin). All part must be typed double-spaced and margins should be left 25-40 mm on all sides. Each copy of manuscript must be good, clear typescript or photoduplicating machine product.

B. Length

Article should be as brief as full documentation allows. Preferably, full papers should not exceed thirty pages (double-spaced typing paper), review articles should not exceed forty (double-spaced typing paper). Figures and tables should be limited to a minimum.

C. Pagination

1. Number all pages consecutively in the upper right corner.
2. The first page should be the title page containing the following information:
   (a) Classification
      (1) Classify the specific field of discipline, such as
         Mathematics Education
         Physics Education
         Biology Education
         Environmental Education
         General Science Education
         Chemistry Education
         Earth Science Education
         Technology Education, etc.
      (2) Classify the specific research domain, such as
         Student Characteristics and Behavior
         Teacher Characteristics and Behavior
         Instructional Materials and Technology
         Instructional Strategies and Environment
         Curricula and Programs
         Teacher Education
         Measurement and Evaluation
         Research Methodology
         Science Education Policy and Practice, etc.
      (3) Classify research methods used, such as
         Correlational
         Experimental

Survey
Observational
Status Study
Historical, etc.
Ethnography
Case Study
Philosophical

(b) Title
Title should be brief, specific, and rich in informative words and should not contain formulas or other symbols.

(c) Author's name

(d) Affiliation
The the department, institute and country of each author should be furnished. If there are several authors with different affiliations, authors should be matched to their respective institutes by means of superscript symbols after the author's names in this order *,**,***, etc. Without special indication, the one star refers to the author to whom correspondence should be addressed.

(e) Mailing address

(f) Running head, with no more than 45 letters including spaces.

3. The second page should include an English abstract and key words. The abstract should be no longer than 300 words. It should state briefly the reason for the work, methods of research, the significant results, and conclusions. The key words should be five to ten words and should be ordered according to importance.

4. The last page should carry the following information in Chinese:
   (a) Title
   (b) Author's name
   (c) Affiliation
   (d) Mailing address
   (e) Abstract.

5. Manuscripts should be arranged in the following order, e.g. title page, English abstract, key words, the text, Chinese abstract, tables and figures. Tables and figures should be on separate sheets, and properly numbered, and their position should be indicated in the text (by typing Fig. –or Table –on a separate line).

D. Heading
The main divisions are suggested to be arranged as follows: INTRODUCTION, METHODS, RESULTS, DISCUSSION, CONCLUSION (if any), ACKNOWLEDGEMENTS, and REFERENCES.

E. Unit of Measure
Metric systems or the international standard system should be used for recording length, area, volume and weight. When used in conjunction with numbers, they should be abbreviated and punctuated (e.g. 3 ml, 5 gm, 7 cm).

F. Footnotes
Footnotes should be kept to a minimum and they should be indicated in the text by superscript numbers.

G. Nomenclature
International standards on nomenclature should be used. The following guide is recommended:

1. *Publication Style Manual of the American Psychological Association*. American Psychological Association.
2. Style manuals or handbooks in the fields of science with international recognition are recommended.

H. Abbreviations
Standard abbreviations for certain substances and units of measure do not need to be defined. Nonstandard abbreviations should be spelled out on first usage. Both standard and nonstandard abbreviations should also conform to international standards. Authors should refer to: *IUPAC Manual of Symbols and Terminology for Physicochemical Quantities and Units*. 1970. Butterworths, London, England; *National Bureau of Standards Special Publication 330*. 1977. Or *Pure and Applied Chemistry*. 1970, 21, 3-44; *Quantities, Units and Symbols*. 1971. Royal Society Symbols Committee, Royal Society, London.

I. Figures and Graphs

1. Figures and graphs should be planned for the smallest possible printed size without hindering clarity.
2. Line drawings should be carefully made in India ink on tracing paper. Original or high quality photographs of the drawings are equally acceptable.
3. All illustrations should be accompanied with describing captions and identified (figure number and author's name) on the reverse side by marking with a soft pencil. Photographs should not be mounted

unless a composite figure is required.

4. Symbols and lettering should be made in India ink and must be proportionate to the size of illustration. The size of the lettering should be chosen as its smallest elements (superscripts or subscripts) will be readable if reduced.
5. Magnification must be indicated with a scale if possible.
6. If the original drawing (or photograph) is submitted, the second copy of the drawing need not be original; clear photoduplicating machine product will also be accepted.
7. Text figures and plates will be reproduced in zinc or copper etchings, or color printing.
8. Figures should be grouped together at the end of the manuscript.

J. Tables

1. Tables should be used only if they present information more effectively than running text.
2. Each table should be typed on a separate sheet, accompanied with a brief caption and be numbered with Arabic numerals. Explanatory matter should be in footnotes, not as a part of the legend.
3. Short or abbreviated column heads should be used, nonstandard abbreviations should be defined in the legend if not defined in the text.
4. Indicate units of measure in parentheses in the heading for each column. Do not change the unit of measure within a column.
5. Tables should be grouped at the end of the manuscript.

K. Acknowledgements

Acknowledgements should be kept to a minimum of words and be given as a paragraph at the end of the text. Acknowledgements to people usually precede those for grant support. Names of grant sources should be spelled out.

L. References

1. References should be cited in the text by the last name of the author (both authors when only two, first author and *et al.* when more than two) and year. If there is more than one reference to the same author(s) and the same year of publication, the references should be differentiated by a, b, etc. e.g., (Jones, 1976); (Jones and Smith, 1976); (Jones *et al.*, 1976); (Reed *et al.*, 1974a), (Reed *et al.*, 1974b), ... as reported by Jones (1976); ... as described by Jones *et al.* (1976).
2. References should be listed in alphabetical order according to author or editor. Give complete information with the title of the paper, report, etc. Do not number references.
3. Literature references should be arranged as follows:

(a) For journals —

Spetch, M.L., & Wilkie, D.M. (1983). Subjective shortening: A model of pigeons' memory for event duration. *Journal of Experimental Psychology: Animal Behavior Processes, 9,* 14-30.

(b) For books —

Bernstein, T.M. (1965). *The careful writer: A modern guide to English usage.* New York: Atheneum.

(c) For technical reports —

Birney, A.J., & Hall, M.M. (1981). *Early identification of children with written language disabilities* (Report No. 81-1502). Washington, DC: National Education Association.

III. PROOFS AND REPRINTS

A. Authors will receive galley-proofs of their papers to check on correct printings. Keep alternations to a minimum, and mark them on the galley, not on the manuscript. Proofs should be checked against the manuscript (in particular all tables, equations, and formulas), and returned as soon as possible.

B. Fifty reprints of each paper will be supplied to each contributor free of charge. Additional copies may be supplied at the author's own expense. The filled-out reprint order form must be returned with the proof. Neither the editors nor the Proceedings office keeps any supply of reprints; request for single copies of papers should be addressed to the author of the paper concerned.

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Topics in Learning Mathematics with Computer

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ABSTRACT

Six topics in applications of the personal computer to the learning of geometry, calculus, combinatorics and linear algebra are discussed.

Key words: computer-oriented method, mathematics learning

I. Introduction

Most university students and many grade school students nowadays enjoy the benefit of convenient access to computers. What do they do after the machine is turned on? They would not be learning mathematics with their computers unless certain proper guidance is provided. To fill this gap, we are conducting exploratory research to investigate the pedagogical issues and educational benefits of introducing a new method of teaching and learning mathematics in schools and universities. The new paradigm is experimental mathematics, and the new exploratory tool is the personal computer. By "new paradigm" we mean computer modeling of mathematical processes to gain insight into their structure and behavior so as to inform and guide mathematical inquiry. This depends fundamentally on the use of personal computers equipped with interactive graphics capability. The goal of our research project is to investigate all areas of mathematics that can be explored through this wonderful tool. This paper may be regarded as a progress report of our findings in this direction. Only mathematically interesting and computationally feasible topics are included in the selection. It is to be reiterated that in performing mathematical experiments, the computer plays the role of a powerful scientific instrument for mathematics exploration in preference to the object of studies. The main thrust of this report is to show that instead of asking the machine to take over the human being in logical reasoning and in theorem proving, the computer can be used in providing motivation to intelligent conjectures in mathematical problem solving. Contrary to the unsophisticated approach to computer learning, students are not simply asked to punch questions in front of a terminal to obtain direct answers, rather, they ought to develop the habit of thinking how the computer can best be used to produce mathematically meaningful guesses. The interactive graphics capability of the computing environment we experience today makes Richard Hamming's words that "the purpose of computing is insight, not numbers"so very true.

II. Number Patterns Associated with Indefinite Integrals

Important concepts in mathematics are often associated with interesting number patterns in which certain algebraic relationships hold for numbers placed according to geometric rules. The first number pattern every grade school pupil memorizes is the multiplication table. In this configuration, all numbers situated on a given row (or column) form an arithmetic progression. In an elementary algebra course, students are exposed to Pascal's Triangle. The Chebyshev polynomials may be introduced by means of the number patterns associated with the way cos nθ is expressed in terms of cosθ . If we were to consult a handbook of mathematical functions, such as (Abramowitz and Stegun, 1967) we would find page after page of number patterns of coefficients of special functions associated with one another. Mathematica Scripta, a journal that ceased publication almost 30 years ago, contains a large amount of number patterns for mathematical recreation. Many profound mathematical theorems crystalized into number patterns that are simple to generate.

We find the ability to generate mathematically meaningful number patterns a rather surprising application of the spreadsheet program. Pascal's Triangle, the easiest nontrivial number pattern, can be generated in a spreadsheet program by entering the constant 1 at B1 cell, entering the formula +B1+A1 at B2 cell, and copying the formula from B2 to B2..Z20. This is just another way to give the instruction that "make every entry the sum of the entry above it and the entry located to its upper left hand side". If the entries were given the "name" $\binom{n}{k}$ as in

$$\begin{array}{lllll}
\binom{0}{0} \\
\binom{1}{0} & \binom{1}{1} \\
\binom{2}{0} & \binom{2}{1} & \binom{2}{2} \\
\binom{3}{0} & \binom{3}{1} & \binom{3}{2} & \binom{3}{3} \\
\binom{4}{0} & \binom{4}{1} & \binom{4}{2} & \binom{4}{3} & \binom{4}{4} \\
 & \cdots
\end{array}$$

the above instruction amounts to

$$\binom{n+1}{k} = \binom{n}{k} + \binom{n}{k-1}.$$

The students are thus led to the discovery of the abstract meaning of this formula by creating number patterns through concrete spreadsheet manipulations.

Browsing through the table of integrals, we often come across many interesting number patterns. For example, in the expression of the indefinite integrals involving exponential functions, we find

$$\int e^{ax}dx = \frac{e^{ax}}{a}$$

$$\int xe^{ax}dx = \frac{e^{ax}}{a^2}(-1 + ax)$$

$$\int x^2e^{ax}dx = \frac{e^{ax}}{a^3}(2 - 2ax + a^2x^2)$$

$$\int x^3e^{ax}dx = \frac{e^{ax}}{a^4}(-6 + 6ax - 3a^2x^2 + a^3x^3)$$

$$\int x^4e^{ax}dx = \frac{e^{ax}}{a^5}(24 - 24ax + 12a^2x^2 - 4a^3x^3 + a^4x^4)$$

The coefficients

$$\begin{array}{lllll}
1 \\
-1 & 1 \\
2 & -2 & 1 \\
-6 & 6 & -3 & 1 \\
24 & -24 & 12 & -4 & 1
\end{array}$$

arouse curiosity. All diagonal terms equal to 1 and each of the rest in the m+1 row is obtained by multiplying -m with the term above it. A moment's reflection will tell us that this is the consequence of the integration by parts formula

$$\int x^m e^{ax}dx = \frac{x^m e^{ax}}{a} - \frac{m}{a}\int x^{m-1}e^{ax}dx.$$

Having obtained that much mathematical insight, the enthusiastic learner should be eager to list the coefficients in a spreadsheet program. The procedures are:

1. List the row numbers 1,2,$\cdots$,10 on the first column (Column A).
2. Enter 1 at cell B1.
3. At cell B2 type in the formula -$a1*b1.
4. Copy the formula from cell B2 to B2..B10
5. Copy the formulas from cell B1..J10 to C2

Would you believe the spreadsheet could lend itself well to the creation of the table of integrals? (See Fig. 1)

We have just applied a simple recursive technique to generate number patterns. We may now proceed with a slightly bolder attempt: to generate a number pattern that corresponds to a double recursion procedure.

From the table of integrals we see the following listing of integrals involving cos x and sin x:

$$\int \cos x\,dx = \sin x$$

$$\int x\cos x\,dx = \cos x + x\sin x$$

$$\int x^2\cos x\,dx = 2x\cos x + (-2 + x^2)\sin x$$

$$\int x^3\cos x\,dx = (-6 + 3x^2)\cos x + (-6x + x^3)\sin x$$

$$\int x^4\cos x\,dx = (-24x + 4x^3)\cos x + (24 - 12x^2 + x^4)\sin x$$

$$\int x^5\cos x\,dx = (120 - 60x^2 + 5x^4)\cos x + (120x - 20x^3 + x^5)\sin x$$

$$\int x^6\cos x\,dx = (720x-120x^3+6x^5)\cos x + (-720+360x^2-30x^4+x^6)\sin x\ .$$

……

$$\int \sin x\,dx = -\cos x$$

$$\int x\sin x\,dx = -x\cos x + \sin x$$

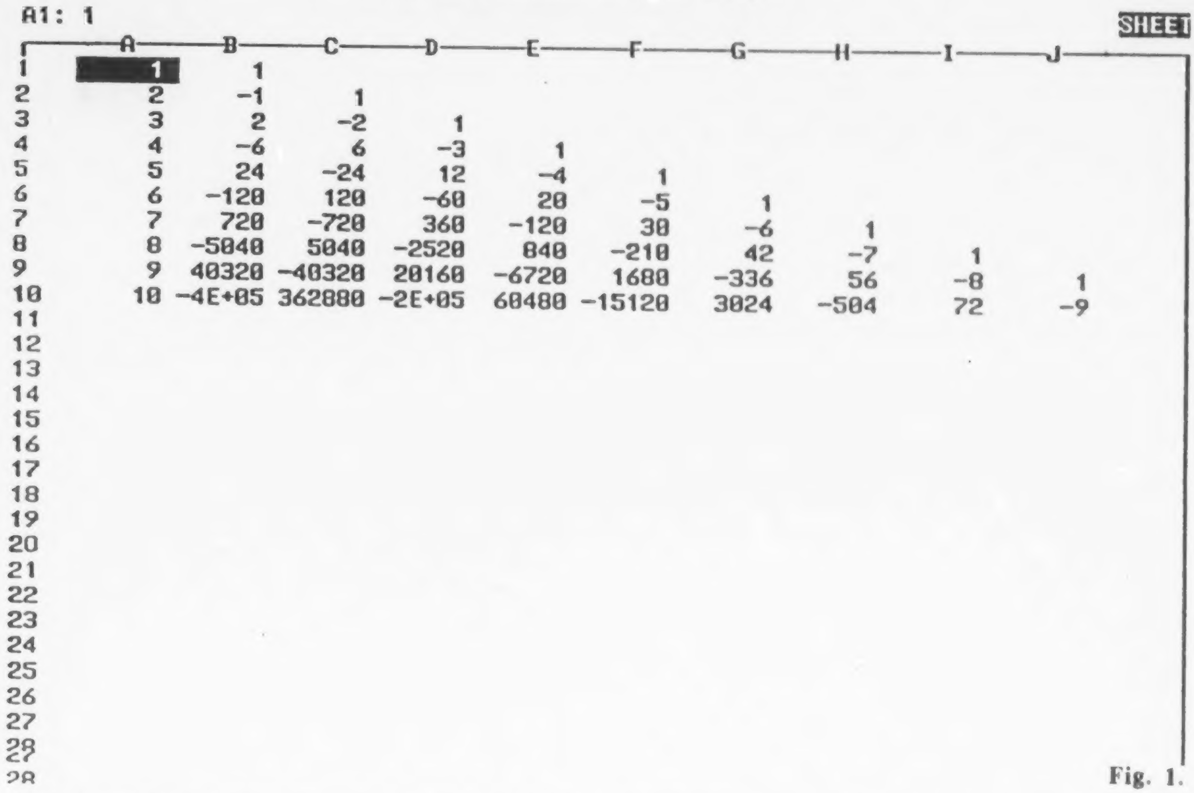
$$\int x^2\sin x\,dx = (2 - x^2)\cos x + 2x\sin x$$

$$\int x^3\sin x\,dx = (6x - x^3)\cos x + (-6 + 3x^2)\sin x$$

$$\int x^4\sin x\,dx = (-24 + 12x^2 - x^4)\cos x + (-24x + 4x^3)\sin x$$

$$\int x^5\sin x\,dx = (-120x + 20x^3 - x^5)\cos x + (120 - 60x^2 + 5x^4)\sin x$$

$$\int x^6\cos x\,dx = (720-360x^2+30x^4-x^6)\cos x + (720x-120x^3+6x^5)\sin x\ .$$



```
A1: 1                                                                    SHEET
       A       B       C       D       E       F       G       H       I       J
1      1       1
2      2      -1       1
3      3       2      -2       1
4      4      -6       6      -3       1
5      5      24     -24      12      -4       1
6      6    -120     120     -60      20      -5       1
7      7     720    -720     360    -120      30      -6       1
8      8   -5040    5040   -2520     840    -210      42      -7       1
9      9   40320  -40320   20160   -6720    1680    -336      56      -8       1
10    10  -4E+05  362880  -2E+05   60480  -15120    3024    -504      72      -9
11
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Fig. 1.

These formulas are the consequences of the integration by parts formula

$$\int x^m \cos x\,dx = x^m \sin x - m \int x^{m-1} \sin x\,dx$$

$$\int x^m \sin x\,dx = -x^m \cos x + m \int x^{m-1} \cos x\,dx.$$

Therefore the corresponding table of coefficients in Fig. 2 can be generated when the spreadsheet is appropriately arranged. This table consists of blocks of coefficients separated by spaces. Each block consists of four rows. The first row of the mth block represents the coefficients of $\int x^m \cos x\,dx$ that correspond to the factor of cos x, and the second row to those of sin x. Similarly the third and the fourth row of the mth block correspond to the coefficients of $\int x^m \sin x\,dx$ that belong to cos x and sin x, respectively. At the beginning, we fill in 1 and -1 in block 0 to reflect the integrals

$$\int x^0 \cos x\,dx = \sin x, \text{ and } \int x^0 \sin x\,dx = -\cos x.$$

Next, we fill in four cells in block 1 dictated by the above two recursive formulas with $m=1$. As in our earlier spreadsheet procedure, the work is completed when we copy the formulas "downwards" then "diagonally".

III. Reflections Inside a Semicircle

Imagine that the boundary of a semicircular region is made of perfectly reflective material, and a beam of light is emitted inside the region. What does the trace of this light ray look like after being reflected? It is doubtful if an intelligent conjecture to this problem could be made without the aid of a computer. Assume that one is equipped with patience and a ruler and compasses, he would probably start by drawing something that looks like:

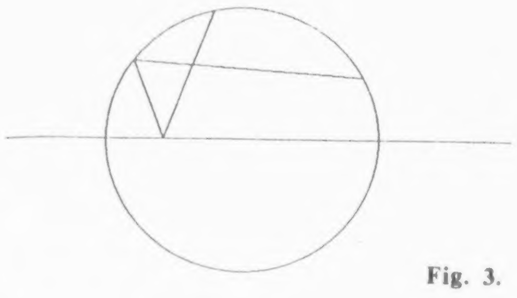
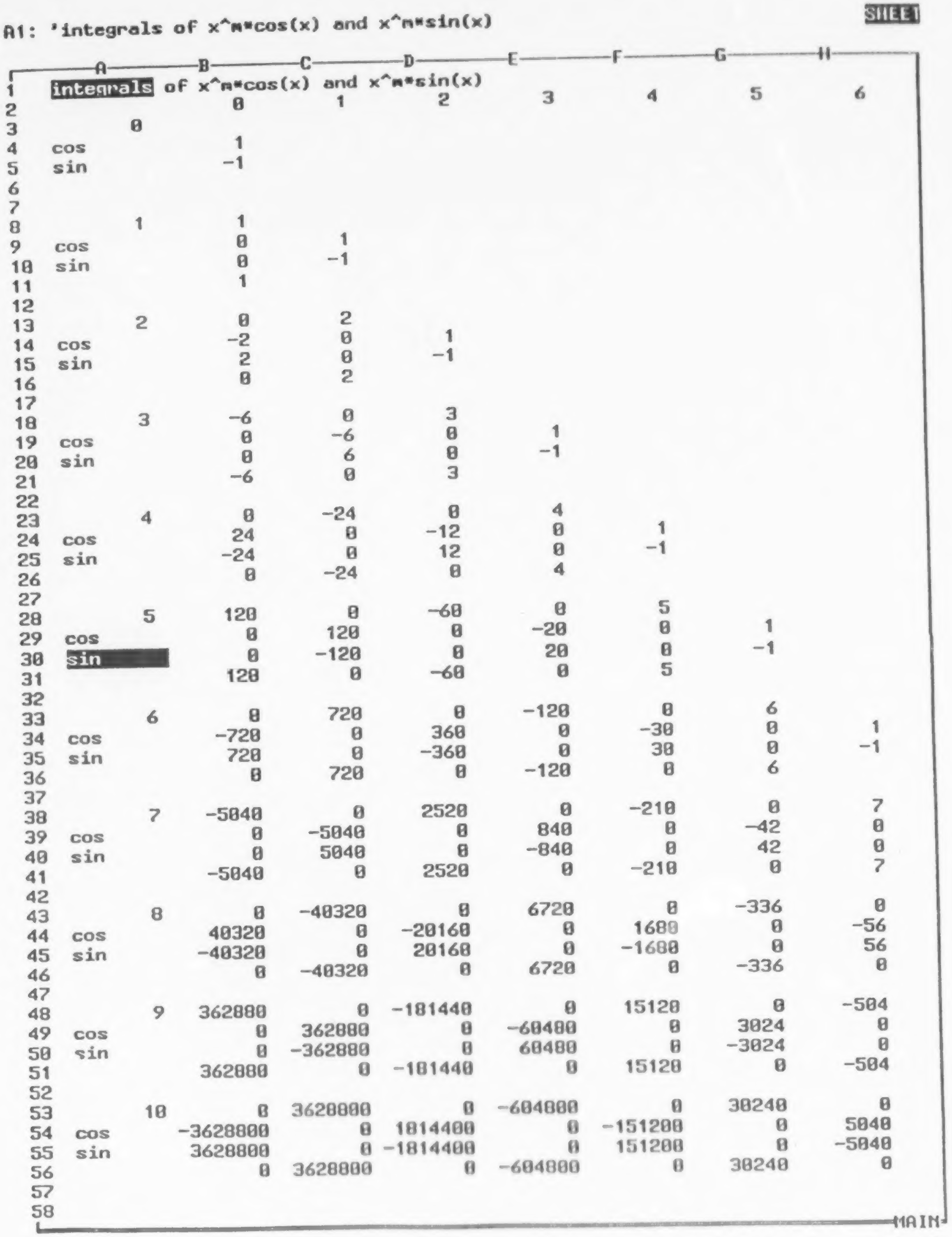


Fig. 3.

After a few more reflections, the drawing appears as:



```
A1: 'integrals of x^m*cos(x) and x^m*sin(x)                           SHEET

    ----A--------B--------C--------D--------E--------F--------G--------H----
 1  integrals of x^m*cos(x) and x^m*sin(x)
 2                    0        1        2        3        4        5        6
 3           0
 4  cos               1
 5  sin              -1
 6
 7
 8           1        1
 9  cos               0        1
10  sin               0       -1
11                    1
12
13           2        0        2
14  cos              -2        0        1
15  sin               2        0       -1
16                    0        2
17
18           3       -6        0        3
19  cos               0       -6        0        1
20  sin               0        6        0       -1
21                   -6        0        3
22
23           4        0      -24        0        4
24  cos              24        0      -12        0        1
25  sin             -24        0       12        0       -1
26                    0      -24        0        4
27
28           5      120        0      -60        0        5
29  cos               0      120        0      -20        0        1
30  sin               0     -120        0       20        0       -1
31                  120        0      -60        0        5
32
33           6        0      720        0     -120        0        6
34  cos            -720        0      360        0      -30        0        1
35  sin             720        0     -360        0       30        0       -1
36                    0      720        0     -120        0        6
37
38           7    -5040        0     2520        0     -210        0        7
39  cos               0    -5040        0      840        0      -42        0
40  sin               0     5040        0     -840        0       42        0
41                -5040        0     2520        0     -210        0        7
42
43           8        0   -40320        0     6720        0     -336        0
44  cos           40320        0   -20160        0     1680        0      -56
45  sin          -40320        0    20160        0    -1680        0       56
46                    0   -40320        0     6720        0     -336        0
47
48           9   362880        0  -181440        0    15120        0     -504
49  cos               0   362880        0   -60480        0     3024        0
50  sin               0  -362880        0    60480        0    -3024        0
51               362880        0  -181440        0    15120        0     -504
52
53          10        0  3628800        0  -604800        0    30240        0
54  cos        -3628800        0  1814400        0  -151200        0     5040
55  sin         3628800        0 -1814400        0   151200        0    -5040
56                    0  3628800        0  -604800        0    30240        0
57
58
                                                                        MAIN
```

Fig. 2.

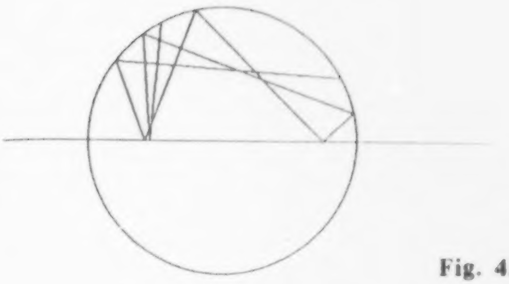


Fig. 4.

If the accuracy prevails, this is what it should look like after a dozen reflections. Still, there is no interesting pattern.

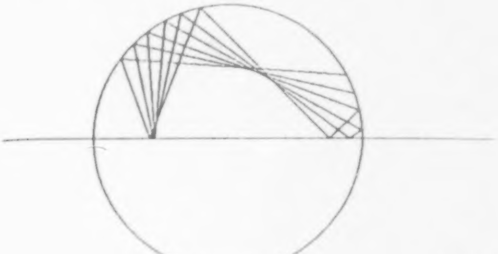


Fig. 5.

It will take a computer to present the insight. Now··· It does not take too much intelligence at all to make a conjecture.

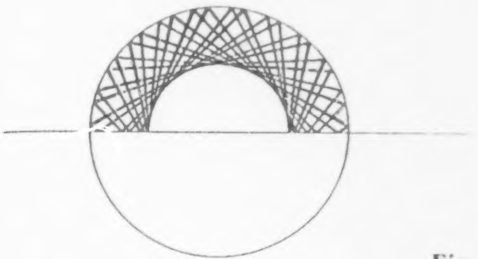


Fig. 6.

After a few more iterations, the drawing could become a work of art.

The program listing written in Turbo Basic that enables the user to see on a visual display the trace of the ray as it undergoes reflections step by step is included in Appendix 1. Whenever the [up] arrow key is pressed, the trace of the light ray will proceed to the next reflection upon the upper perimeter of the semicircle. Pressing the [down] arrow key will stop the program.

We took advantage of the symmetric property of a

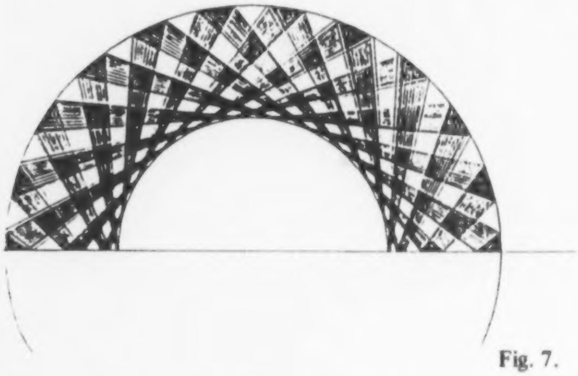


Fig. 7.

semicircle in creating this program. It would be a much more challenging task to write a program to display the reflection of light ray inside an arbitrarily shaped (non simply connected) region.

IV. Bernstein–Bezier Polynomial Curve

For any t and any positive integer n, we have the identity

$$1 = [t + (1-t)]^n = \sum_{k=0}^{n} \binom{n}{k} t^k (1-t)^{n-k}.$$

This formula expresses the fact that the function constant 1 is a sum of the n+1 polynomial functions $\binom{n}{0}t^0(1-t)^n$, $\binom{n}{0}t^1(1-t)^{n-1}$, ···, $\binom{n}{n}t^n(1-t)^0$. Trying to find a polynomial function approximating a continuous function uniformly, S. N. Bernstein came up with the idea of constructing the Bernstein polynomial

$$p(t) = \sum_{k=0}^{n} \binom{n}{k} t^k (1-t)^{n-k} f(\tfrac{k}{n})$$

for a given continuous function f defined on [0,1]. It expresses the fact that at each point t, the value p(t) is a suitable convex combination of the fixed values f(0), $f(\frac{1}{n})$, ···, f(1). It took almost 70 years before this formula was reexamined and made suitable for the design of automobiles. Bezier modified Bernstein's formula and considered the expression given by

$$\vec{P}(t) = \sum_{k=0}^{n} \binom{n}{k} t^k (1-t)^{n-k} \vec{Q}_k$$

for any given vectors $\vec{Q}_0, \vec{Q}_1, \cdots, \vec{Q}_n$ (taken from the same vector space). This curve $\vec{P}(t)$ is now called the Bernstein-Bezier polynomial curve. We see at once that the Bernstein-Bezier polynomial curve enjoys the following properties:

1. $\vec{P}(0) = \vec{Q}_0$, $\vec{P}(1) = \vec{Q}_n$.
2. For $0 \leqslant t \leqslant 1$, the vector $\vec{P}(t)$ lies in the convex hull of the vectors $\vec{Q}_0, \vec{Q}_1, \cdots, \vec{Q}_n$.
3. $\vec{P}'(0) = n(\vec{Q}_1 - \vec{Q}_0)$, $\vec{P}'(1) = n(\vec{Q}_n - \vec{Q}_{n-1})$.

Statements 1 and 3 say that this curve passes through the points $\vec{Q}_0$ and $\vec{Q}_n$ with the tangents in the directions of Q_0Q_1 and $Q_{n-1}Q_n$. In case $n = 3$ the resulting curve takes the form

$$\vec{P}(t) = (1-t)^3\vec{Q}_0 + 3(1-t)^2t\vec{Q}_1 + 3(1-t)t^2\vec{Q}_2 + t^3\vec{Q}_3$$

and is called the Bezier cubic curve. This may be expressed in the following matrix notation:

$$\vec{P}(t) = [1\ t\ t^2\ t^3] \begin{bmatrix} 1 & 0 & 0 & 0 \\ -3 & 3 & 0 & 0 \\ 3 & -6 & 3 & 0 \\ 1 & 3 & -3 & 1 \end{bmatrix} \begin{bmatrix} Q_0 \\ Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} .$$

and statements 1 and 3 above become

$$\vec{P}(0) = \vec{Q}_0,\ \vec{P}(1) = \vec{Q}_3,\ \vec{P}'(0) = 3(\vec{Q}_1 - \vec{Q}_0),\ \vec{P}'(1) = 3(\vec{Q}_3 - \vec{Q}_2).$$

It is thus an easy matter to construct the Bezier cubic curve once the initial position P(0), the final position P(1), the initial velocity P′(0) and the final velocity P′(1) are given.

In a computer aided design (CAD) program, it is a fundamental task to draw a smooth curve that meets the requirement of passing through two given points and be tangent to specified given vectors there. The Bezier cubic curve discussed above furnishes a neat solution to the problem. This application of a linear algebra concept (convex combinations) to CAD can aptly be demonstrated with a spreadsheet program. We arrange the spreadsheet so the initial position P(0), the final position P(1), the final velocity P′(1) are "fixed", and the initial velocity P′(0) is allowed to "vary" along the "unit circles", so each time the RECALC key is pressed a cubic curve corresponding to the solution of a new initial velocity is displayed. From the drawings (Fig. 8-14) experimenters are invited to observe the convex hull property promised in theory.

The Bernstein-Bezier polynomial curve is a standard topic in the works of computational geometry and in the theory of geometric designs. Bezier's original work can be found in (Bezier, 1972).

V. Generation of Permutations

According to G. Polya, combinatorics can be classified into three types: enumerative, existential, and constructive (Polya, 1983). Enumerative combinatorics deals with the counting of combinatorial objects. Existential combinatorics studies the existence or the nonexistence of combinatorial configurations. Constructive combinatorics deals with the methods for actual finding specific configurations, as opposed to merely demonstrating their existence theoretically. Hence constructive combinatorics may be regarded as one corner stone of the freshman-sophomore university discrete mathematics curriculum. Most of the current popular textbooks in discrete mathematics and in combinatorics were written in the days before the personal computer was hardly a household name and perhaps the authors thought that Fortran was the only programming language good for scientific calculations. Is this the reason why the constructive aspect of combinatorics has been neglected in current combinatorial mathematics courses? We now enjoy the privilege of convenient access to powerful micro computers equipped with user friendly software. It is time for us to rethink the possibilities of including constructive mathematics topics in basic mathematics courses.

Let us now single out one such constructive combinatorics topic and examine the various implementations: how to generate all n! permutations of the set {1,2,⋯,n}? The first book that ever included a Fortran code to solve this problem was "Combinatorial Algorithms", by A. Nijenhuis and H. S. Wilf (1975). In another textbook, with the same title as Nijenhuis and Wilf's, E. Reingold, J. Nievergelt and N. Deo in 1977, investigated several types of algorithms dealing with the same problem without giving any computer codes. In the 1986 textbook "Constructive Combinatorics", it was distressing to see that the authors D. Stanton and D. White failed to motivate their readers with insight into this problem. Of the many methods of generating permutations, we find the one mentioned in "Algorithmics, Theory and Practice", by G. Brassard and P. Bratley (1988) the most concise. On page 186 of the book we find

```
Procedure perm(i)
    if i = n then use(T) {T is a new permutation}
        else for j <-i to n do exchange T[i] and T[j]
            perm(i+1)
            exchange T[i] and T[j]
```

Here T[1..n] is a global array initialized to [1,2,⋯,n] and the initial call is perm(1).

From this compact description, we managed to convert the algorithm into the following Turbo Basic code. This demonstrates how easy it is to implement constructive combinatorics under the environment provided by a well structured programming language such as Turbo Basic.

```
'Generation of permutations, Ref. G. Brassard & P.
'Bratley, Algorithmics p.186
```

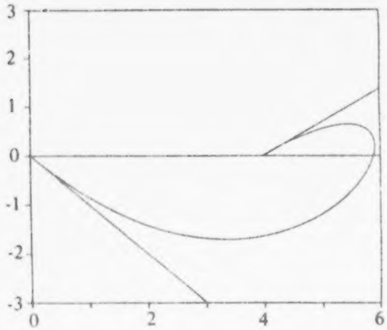


Fig. 8.

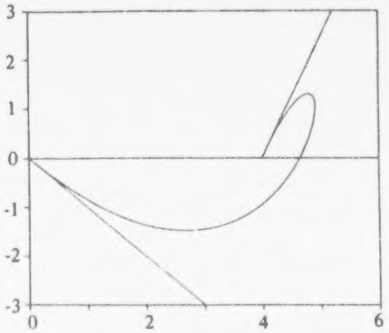


Fig. 9.

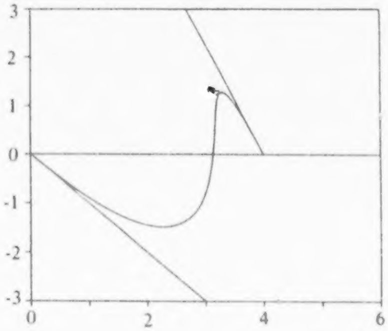


Fig. 10.

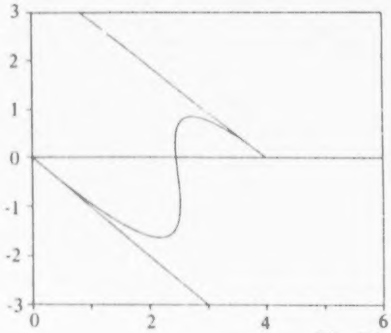


Fig. 11.

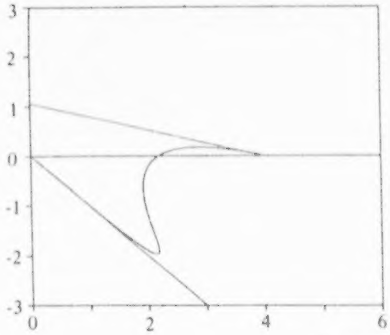


Fig. 12.

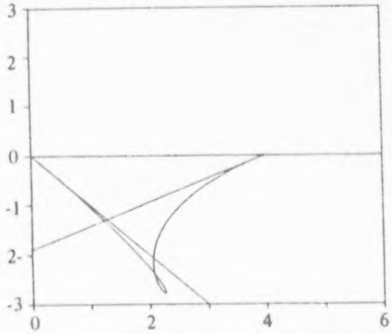


Fig. 13.

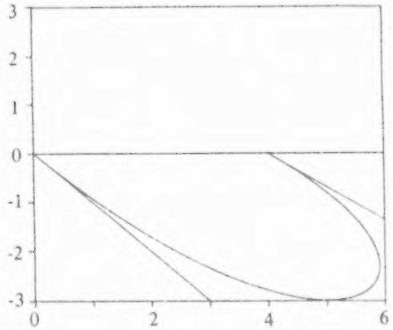


Fig. 14.

```
cls
sub perm(k)
shared v(),n
local t
      if k= n then
            call dd
            else
                  for t=k to n
                        swap v(t),v(k)
                        call perm(k+1)
                        swap v(t),v(k)
                  next t
      end if
end sub
sub dd   'subroutine to display the resulting permut-
'ations
shared v(), n
for i=1 to n:?v(i); :next i
?
end sub
n=5   'number of elements in question
dim v(n)
for i=1 to n:v(i)=i:next i   'initialize v to be the identity
call perm(1)         'the whole "program" consists of
'only one line!
```

This program is so short that any beginning student of combinatorics can type it and try to experiment with various choices of n with a personal computer equipped with Turbo Basic. The process of carrying out this experiment will enable him to understand, among other things, the abstract aspect of mathematics.

An algorithm similar to the above is given in R. Sedgewick's Algorithms. The whole "program" appears as:

```
procedure visit(k:integer);
var t: integer;
begin
id:=id + 1; val[k]:=id;
if id=V then writeperm;
for t:=1 to V do
     if val[t]=0 then visit(t);
id:=id-1; val[k]:=0
end;
```

This procedure can be translated into the following Turbo Basic code:

```
' Generation of permutations, Ref: Sedgewick p.628
cls
sub visit(k)
shared now,v(),n
local t
now=now+1
v(k)=now
if now=n then call dd
for t=1 to n
  if v(t)=0 then call visit(t)
next t
now = now -1
v(k)=0
end sub
sub dd    'print out the permutation
shared v(),n
for i=1 to n:?v(i)::next i
?
end sub
now=-1
n=4
dim v(n)
call visit(0)   'one line program
```

It is possible to devise an algorithm that generates the collection of permutations in lexicographic order. The principle behind this procedure is described in A. Tucker's "Applied Combinatorics" (1980):

> "To determine the permutation following the permutation $a_1 a_2 a_3 \cdots a_n$ in lexicographic order we start from the right end of the sequence and moving left, look for the first pair a_i, a_{n+1} such that $a_i < a_{n+1}$ (and $a_{i+1} > a_{i+2} > a_{i+3} > \cdots > a_{n-1} > a_n$). Then the next larger sequence is obtained by placing the minimum of the set $\{a_j : a_j > a_i$ and $j > i\}$ in position i and placing the remaining digits $a_i, a_{i+1}, \cdots, a_n$ (excluding the one digit put in position i) in positions i+1 through n in increasing order. With this rule for the next larger lexicographic sequence, it is easy to write a program to list all permutations of an n set in lexicographic order."

The author thus did not bother to create the actual code to implement the algorithm. Interpreting Tucker's idea we have derived the following program that runs under Turbo Basic:

```
cls
n=4
for i=1 to n:a(i)=i:next i
sub nextperm
shared a(),n
for i=n-1 to 1 step -1
if a (i)<a(i+1) then
     for h=n to i+1 step -1
          if a(i)<a(h) then
               swap a(h),a(i)
               for h=i+1 to n
                    tmp(h)=a(h)
               next h
               for h=i+1 to n
                    a(h)=tmp(n+i+1-h)
               next h
```

```
            end if
        next h
    for i=1 to n
    ?a(i);
    next i
    ?
    exit sub
    end if
    next i
    end sub
    for i=1 to 26
    call nextperm
    next i
```

This is what appears on the screen after executing this program:

```
1  2  4  3
1  3  2  4
1  3  4  2
1  4  2  3
1  4  3  2
2  1  3  4
2  1  4  3
2  3  1  4
2  3  4  1
2  4  1  3
2  4  3  1
3  1  2  4
3  1  4  2
3  2  1  4
3  2  4  1
3  4  1  2
3  4  2  1
4  1  2  3
4  1  3  2
4  2  1  3
4  2  3  1
4  3  1  2
4  3  2  1
```

Pure mathematicians will enjoy the thrill of abstraction. The constructive mathematicians will enjoy further the thrill of converting abstract concepts into concrete computer programs that actually run.

VI. Robinson's Construction

Counting is a basic mathematical activity from which all numeral systems of the civilized world were derived. Children learn to count before starting kindergarten. Yet some of the most remarkable open questions in mathematics deal with counting. Can the computer help people count? Most of the mathematical software address to the need of calculating, rather than counting. It would be a fruitful investigation to see how the computer may increase our understanding of the process of counting. Let us take the following question in combinatorics that deals with the counting of certain abstract mathematical objects: How many permutations of 1, 2, ⋯,n are there that have a longest increasing subsequence of length p and a longest decreasing subsequence of length q? Asking the computer to perform the naive counting by going over all permutations of n one by one to see which ones actually have the required property is an impossible task even for n = 20. We now illustrate a computer related activity which enables us to understand a clever method of solving this problem. In this way, the computer does not do the counting but helps people understand the counting method.

Fix a positive integer n. For any given partition

$$\alpha_1 + \alpha_2 + \cdots + \alpha_m = n$$
$$\alpha_1 \geq \alpha_2 \geq \cdots \geq \alpha_m = n$$

of n an array $((k^i_j))$ such that the i-th row $(k^i_1, k^i_2, k^i_3, \cdots, k^i_{\alpha_i})$ of the array contains exactly α_i integers is called a tableau associated with this partition. The tableau is called normal if

(1) the k^i_j's are all distinct;

(2) if $i > j$ then $k^i_s > k^j_s$ for all s;

(3) if $i > j$ then $k^t_i > k^t_j$ for all t.

G. de B. Robinson gave a construction in 1938 in which any sequence φ of distinct integers is associated injectively with a pair $P(\varphi)$, $Q(\varphi)$ of normal tableaus with the same diagram. We now describe this construction in ordinary language and show how this abstract mathematical procedure may be transformed into instructions understood by the computer.

Let T be a normal tableau formed with distinct integers $k_1, k_2, \cdots, k_n$. If x is distinct from any of the k_i's then a new tableau can be formed using the following rules:

(1) If possible, insert x in the first row by replacing the smallest k_i in the first row that is greater than x by x. If no such k_i exists, add x to the end of the first row.

(2) If x replaces k_i in the first row, insert k_i, following rule (1), in the second row and so on.

This new tableau is denoted by $(T \leftarrow x)$. Notice that $(T \leftarrow x)$ is again a normal tableau.

For the given sequence φ of distinct integers $k_1, k_2, \cdots, k_n$, let $P(\varphi)$ denote that tableau

$$[((k_1) \leftarrow k_2) \leftarrow k_3] \leftarrow k_4 \cdots.$$

Let $Q(\varphi)$ be the tableau with the same diagram as $P(\varphi)$, obtained by inserting the integer i into the box which is added to the diagram when the integer k_i is first inserted in $P(\varphi)$.

Conversely, the initial sequence φ can be reconstructed by reversing the above procedure.

In view of the fact that the number of columns of $P(\varphi)$ is equal to the length of the longest increasing subsequence of φ while the number of rows of $P(\varphi)$ is equal to the length of the longest decreasing subsequence of φ. Robinson's construction is important in establishing the following theorem due to C. Schensted:

Theorem. The number of permutations of $1, 2, \cdots, n$ that have a longest increasing subsequence of length p and a longest decreasing subsequence of length q is obtained by counting the standard tableaus associated with the partitions of n into q parts, the greatest part being p and summing the squares of the numbers obtained.

For the detail discussion of Robinson construction and related concrete examples, the readers may consult (Berge, 1971).

The code below, written in Turbo Basic, establishes the one to one correspondence given by Robinson. In this program, we first generate a random permutation of the integers $1, 2, \cdots, 18$ and then the normal tableaus $P(\varphi)$ and $Q(\varphi)$ are listed. Then from $P(\varphi)$ and $Q(\varphi)$ we reconstruct the original sequence φ back.

```
'Robinson Construction
'p.66 of C. Berge: Principles of Combinatorics
cls
randomize timer
n=18
dim p(n,n),q(n,n),b(n),c(n),i(n),j(n),d(n)
sub subs(r,x)
shared p(),k,q()
local s,y
' s is the length of the row r
s=p(r,0)
if x>p(r,s) then
            p(r,s+1)=x
            p(r,0)=s+1
            k=k+1
            q(r,s+1)=k
            exit sub
else
            for t=s to 1 step -1
            if p(r,t)<x then goto qq:
            next t
            qq:
            swap x,p(r,t+1)
            call subs(r+1,x)
end if
end sub
'Generation of a random permutation
for j=1 to n
b(j)=j
next j
for j=1 to 100
q=ceil(rnd*n)
w=ceil(rnd*n)
swap b(q),b(w)
next j
for j=1 to n
?b(j);
next j
?
?
for j=1 to n
call subs(1,b(j))
next j
for i=1 to n
for j=1 to p(i,0)
locate 5+i,3*j
?p(i,j);
next j
?
next i
for i=1 to n
for j=1 to p(i,0)
locate 5+i,3*j+40
?q(i,j);
next j
?
next i
'-=-=- Now, for the reverse operation.
'-=-=- First, reshape p(i,j) into an array c(k)
'-=-=- Also, create two arrays i(k), j(k) to indicate
'(i,j) position of c(k)
for i=1 to n
for j=1 to n
            c(q(i,j))=p(i,j)
            i(q(i,j))=i
            j(q(i,j))=j
next j
next i

for k=n to 1 step -1
x=p(i(k),j(k))
'The length of row i(k) is to be reduced by one!
p(i(k),0)=p(i(k),0)-1
for h=i(k)-1 to 1 step -1
          for g=p(h,0) to 1 step -1
                      if p(h,g)<x then:swap
x,p(h,g):goto xx:
            next g
xx:
next h
d(k)=x
next k
for k=1 to n
?d(k);
next k
```

The output of this program appears as:

```
2 4 11 15 13 1 9 16 12 7 14 5 10 6 3 17 18 8

1 3 5 6 8 17 18          1 2 3 4 8 16 17
2 4 10 14                5 7 9 11
7 12 16                  6 13 18
9 13                     10 14
11                       12
15                       15

2 4 11 15 13 1 9 16 12 7 14 5 10 6 3 17 18 8
```

VII. Generation of a Maze

In graph theory, the most fundamental of all types of graphs is a tree. A graph with no cycle is called acyclic, and a tree is a connected acyclic graph. Like many important mathematics concepts, a tree possesses the mini-max property: It is the minimal member among the family of all connected graphs (in other words, any proper subgraph of a tree must be disconnected); it is at the same time the maximal member among the family of all acyclic graphs containing all nodes (Any spanning graph cannot be acyclic unless it is a tree.) It is not difficult to see that every tree can be embedded in a plane. When embedded in a plane, the complement of a tree is connected. Also in a tree any two nodes are connected by a unique path. We may take the last two sentences to be the guiding principles in constructing a maze having a unique solution.

A maze is any network of walled pathways that can be of any geometric shape. In order to take advantage of the two dimensional array structure found in most computer languages, we only focus our attention on the construction of a planar maze having all walls crossing at right angles. If, in addition, we require the walls to form a tree (in the sense of graph theory) then no region would be encircled; there is no inside or outside "components" since the complement of a tree is connected, (a fact that requires the powerful Jordan Curve Theorem to settle!). We can therefore formulate the situation as a problem in mathematical experiment by designing a program that would randomly generate a tree T passing through all the lattice points (points whose coordinates are integers) lying outside the square $R = [15,25] \times [15,25]$ and inside the square $S = [0,40] \times [0,40]$. With this tree as the walls of a maze, we next ask for the (unique) "solution", which is formed by a simple polygonal line joining a point inside R to anywhere outside S without meeting any point of T. This exercise will at once lead us to consider the "depth-first search" algorithm. In order to generate the maze we simply allow ourselves to walk randomly among the lattice points between the two squares one step at a time (either horizontally or vertically) and keep track of the coordinates we have visited, avoiding visiting the same node twice. Whenever a dead end is encountered, we just backtrack to the first node that is available to form a new branch. The procedure is repeated recursively until no more new branches may be formed. The resulting figure, being a maximal acyclic spanning graph, must be a tree. What's so interesting about this exercise is that it enlightens us to realize that the very algorithm used for the creation of the walls of the maze can be used again to find the solution of the maze! There is nothing better to help one's understanding of the depth-first search algorithm than trying to implement the above maze creation-solution computer exercise. Here is the actual Turbo Basic instructions:

```
n=40:nn=n+1
$stack 32700
randomize timer
screen 12
window(0,0)-(n+1,n+1)
cls
paint (1,1),1
dim a(nn,nn),p(nn•nn),q(nn•nn),b(2•nn,2•nn),pp(
4• nn•nn),qq(4•nn•nn)
for i=0 to nn
for j=0 to nn
if i<1 or i > n or j<1 or j>n then a(i,j)=1 else
a(i,j)=0
next j
next i
for i=n/2-2 to n/2+2
for j=n/2-2 to n/2+2
a(i,j)=1
next j
next i
x=ceil(rnd•n):y=ceil(rnd•n):pset(x,y):k=1:a(x,y)=1:
p(1 )=x:q(1)=y:b(2•x,2•y)=1
while k<n•n-25
while a(x+1,y)+a(x-1,y)+a(x,y+1)+a(x,y-1)=4
' Pick another at random
s=ceil(rnd•k)
x=p(s):y=q(s)
wend
pset(x,y):b(2•x,2•y)=1
while a(u,v)=1
r=rnd•4
select case r
case >3
u=x+1:v=y
case <1
u=x-1:v=y
```

```
case <1
u=x-1:v=y
case 1 to 2
u=x:v=y+1
case else
u=x:v=y-1
end select
wend
b(x+u,y+v)=1
x=u:y=v:k=k+1:a(x,y)=1:line-(x,y):
p(k)=x:q(k)=y:b(2*x,2
*y)=1
wend
while not instat :wend
beep
for i=n-4 to n+4
for j=n-4 to n+4
b(i,j)=1
next j
next i
x=n-5:y=n-3:circle(x/2,y/2),.1,11:
s=1:b(x,y)=1:pp(1)=x:
qq(1)=y:u=x:v=y
while x>1 and x<n*2+1 and y>1 and y<n*2+1
while b(x+1,y)+b(x-1,y)+b(x,y+1)+b(x,y-1)=4
b(x,y)=1
circle(x/2,y/2),.1,2
s=s-1
x=pp(s):y=qq(s)
wend
circle(x/2,y/2),.1,11
b(x,y)=1
while b(u,v)=1
u=x:v=y
r=rnd*4
select case r
case >3
u=x+1:v=y
case <1
u=x-1:v=y
case 1 to 2
u=x:v=y+1
case else
u=x:v=y-1
end select
wend
x=u:y=v:s=s+1:b(x,y)=1:pp(s)=x:qq(s)=y
wend
beep
```

References

Abramowitz, M. and Stegun, I. (1967). *Handbook of mathematical functions*. New York, Dover.

Ayres, F. (1952). *Theory and problems of differential equations*. New York, Schaum.

Berge, C. (1971). *Principles of combinatorics*. New York, Academic Press.

Bezier, P. (1972). *Numerical control in automobile design and manufacture of curved surfaces*. Curved Surfaces in Engineering, IPC Science and Technology Press.

Nijenhuis, A. and Wilf, H. (1975). *Combinatorial algorithms*. New York, Academic Press.

Polya, G., Tarjan, R. and Woods, D. (1983). *Notes on introductory combinatorics*. Boston, Birkhaeuser.

Reingold, E., Nievergelt, J. and Deo, N. (1986). *Combinatorial algorithms*. Englewood Cliffs, Prentice Hall.

Stanton, D. and White, D., (1986). *Constructive combinatorics*. New York, Springer.

Tucker, A.(1985). *Applied combinatorics*. New York, John Wiley & Sons.

Appexdix 1. Listing of Turbo Basic showing reflections inside a semicircle

```
cls
locate 10,10
? ″Reflections Inside a Semicircle″
locate 12,10
? ″press [up] arrow to follow the light ray″
locate 14,10
? ″press [down] arrow to end″
while not instat
wend
screen 12
window(-2,-1)-(2,2)
cls
circle(0,0),1,,,,1
line (-10,0)-(10,0)
key(11) on
key(14) on
p=2
t=0.5
preset(cos(t),sin(t))
yy:
on key(11) gosub xx:
on key(14) gosub ee:
goto yy:
xx:
t=t+p
select case t
case > atn(1)*4
x1=cos(t)
y1=sin(t)
x2=cos(t-p)
y2=sin(t-p)
line-((x1*y2-x2*y1)/(y2-y1),0)
t=atn(1)*8-t
p=-p
case < 0
x1=cos(t)
y1=sin(t)
x2=cos(t-p)
y2=sin(t-p)
line-((x1*y2-x2*y1)/(y2-y1),0)
t=-t
p=-p
end select
x=cos(t)
y=sin(t)
line-(x,y)
rr:
return
ee:
end
```

電腦在學習數學的使用

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摘 要

本文討論並列舉六項實例說明如何應用電腦於學習幾何、微積分、組合學及線性代數。

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Understanding in Multiple Ratio and Non-linear Ratio

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ABSTRACT

A hierarchy of four levels of understanding in simple ratio were estalished by one of our previous studies. The present study developed three more advanced understanding levels beyond those four levels. Among the various domains of advanced proportional problems, multiple ratio, i.e. $a \propto bc$, and the non-linear ratios, i.e. $y \propto kx^2 / kx^3$, were chosen as the concept domains for this study. 1539 subjects who are representative of Taiwan senior high school students aged 16 and 17 took part in this study.

These three advanced hierarchical levels are linked nicely with the four levels of understanding simple ratios. They are characterized strongly by the different kinds of relationships between quantities involved in the tasks, such as inverse ratio, composition of two positive ratios, composition of positive and inverse ratios, the quadratic relation and the cubic relation. The reasoning strategies used by students and the meaning of the levels of understanding were analysed in this paper.

Key words: ratio and proportion, advanced mathematics thinking, understanding levels

I. Introduction

One of our previous studies investigated levels of understanding in ratio and proportion at junior secondary level (aged $13 \sim 15$) in Taiwan (Lin 1988a). It was one of several replicated studies of the Concepts in Secondary Mathematics and Science (CSMS) programe in England (Hart, 1981). A hierarchy including four levels of understanding simple ratio tasks was developed. A student who is at the highest level of understanding (level four) can apply correct multiplicative strategies, such as the ratio formula, the multiplier method and the unitary method to solve simple ratio tasks with non-integer rates in different settings (Lin, 1987). Almost all the research on ratios in the literature dealt with the concept of ratio to the extent of this level (c.f. Tournaier & Pulos, 1985).

In 1988, I proposed a question: does there still exist a developmental hierarchy of understanding of ratio beyond level four? At the same time, I had shown tentative results of an investigation on this question, and suggested that the answer of this question might be affirmative (Lin, 1988b).

A two-year research project was established in Taiwan to investigate this question systematically. During the first year of investigation, five domains of advanced ratio and proportion tasks were developed (Lin, 1990a), namely:

(1) The parameter of ratio.

---

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(2) The duality between *examples,concepts and theorems* of proportional relations.
(3) The linear interpolation method with respect to different representations of a function.
(4) Multiple ratio, i.e. $a \alpha b^{*}c$, where a,b,c are variables.
(5) Non-linear ratio, i.e. $y \alpha x^{n}$, where x,y are variables.

The tasks in domains (1) ~ (4) are all concerned with linear proportionality. The non-linear ratio tasks were developed with the following considerations.

(a) From a symbolic generalization point of view, the relation $y=kx^{n}$, $n=2,3$, is a natural generalization of the relation $y=kx$.
(b) Non-linear reasoning is used in everyday life. There are situations in everyday life in which the change of a one dimensional measurement is used to represent the change of a two or three dimensional measurement, e.g. the size of a round cake is represented by its diameter rather than by its volume. To make different sized cakes according to a given recipe, it is necessary to apply the non-linear proportional relation.
(c) The reasoning processes of non-linear and linear ratio are parallel.

Mathematics understanding is multi-dimensional (Usiskin, 1987). Usiskin distinguished four dimensions of understanding mathematics, namely Skill, Property, Use and Representation. He argued that the school mathematics curriculum needs all of these dimensions and that levels of understanding are meaningful within the same dimension only.

Out of the above five domains of advanced proportional tasks described above, which shall be the candidates such that the understanding of tasks in those domains and the tasks of simple ratios used in our previous study could be structured as uni-dimensional?

To solve tasks in the domains of multiple-ratio and non-linear ratio, one has to recognize either one more relation or a more general relation then solving simple ratio tasks. Moreover, our interviews showed that many strategies used by students in solving multiple and non-linear ratio tasks can be analogically linked to their strategies in solving simple ratio tasks. Therefore, multiple ratio and non-linear ratio were combined to form one test, and was called the "Advanced Proportional Reasoning" test (Lin, 1990b). This test was conjectured to be a uni-dimensional understanding test. This conjecture will be examined in this paper. The studies on the other three domains will be reported elsewhere.

II. Methodology

The aims of this study were:
-to examine and describe the hierarchical levels of understanding simple ratios, multiple ratios and non-linear ratios.
-to describe the methods Taiwan students use to solve multiple ratio and non-linear ratio problems, and the errors they make.

There were 25 items in the test. Six/nine/nine of them were simple/multiple/non-linear ratio items respectively. Five simple ratio items were the items used to describe "understanding of level four" in the previous study. One of these five items was a continued ratio item. Another continued ratio item was developed with the same context, i.e. a recipe for punch.

Each of the new items developed was determined using the following two procedures:
-interviews with about 40 students to check that the item's meaning is well understood and to find out the strategies students used;
-pilot testing two classes to check that the objective of the item tested was achieved.

A two-stage stratified proportional sampling procedure was applied, as follows:
-All 160 senior high schools in Taiwan were stratified into five strata according to the performance of each school in a national study "Survey Study on Senior High School Students' Understanding of Basic Science" (Yang, 1988).
-Simple random sampling of a few schools and students from each stratum according to the student population. Whenever a school was selected, 4 to 8 students from each class in this school were selected randomly.

As a result, 11 schools and 1539 subjects aged 16-17 (about 1.1% of the totle sample), were selected. The tests were administered by at least one project researcher in each school and some teachers from that school. Each test last 110 minutes. All tests were completed during the same month. For each item, all subjects were asked to write down the process they used in solving the item.

III. Task Analysis

The tasks of multiple ratios and non-linear ratios which were developed for this study are as follows. An analysis of these items are described briefly in Table 1.

"Advanced Proportional Reasoning Test"

<5> Ming and Huei go to school by the same route.
Ming leave at 7:05.
Huei leave at 7:12.
Huei catches up with Ming at 7:25.

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Find the ratio of Ming's average speed to Huei's average speed?

<6> The power consumption of some bulbs during a period is 6 units.

(1) If the number of bulbs is halved, and the time period increased 3 times, find the number of power units consumed?

(2) If the number of bulbs is increased 4 times, and 4 power units are consumed, find how long the bulbs are alight?

<7> The distance between town A and B is 72 km. It takes Ming 1 hr. 54 min. to go from A to B by motorcycle. On the return journey, Ming increases his speed by 20%. How long does the return journey take?

<8> To increase the temperature of 50L of water by 5.7℃ requires 30L of gas.

(1) How much gas does it take to increase the temperature of 25L of water by 17.1℃?

(2) If 20L of gas are used to heat 200L of water, by how much will its temperature increase?

<9> A father and his son ride different sized bicycles to a picnic.

In 7 revolutions, the big bicycle travels the same distance as the small bicycle travels in 11 revolutions.

Also, the time the father takes to cycle 5 revolutions is the same as the son takes to cycle 8 revolutions.

(1) Find the ratio of the radius of the big bicycle to that of the small bicycle?

(3) Find the ratio of the speed of the big bicycle to that of the small bicycle?

<10> The following recipe is for a round chocolate cake of diameter 6 inches:

7/4	cups flour	4	eggs
6	OZ chocolate	3/2	cups sugar
1/2	teaspoons soda powder		

Assuming the cake has the same height,

(1) How many cups of flour do we need to make a cake with diameter 12 inches?

(2) What sized cake would be made with 36 eggs?

(3) What sized cake would be make from 18 OZ chocolate?

(4) (a) Find the maximum size of cake which can be made with 9 eggs and 14 OZ chocolate?

(b) How much chocolate or eggs will be left over?

<11> A new train is testing its speed limits.

To do this, a time-marker is placed every 100 km.

The train travels with constant acceleration, and the first time marker shows 1.28 secs.

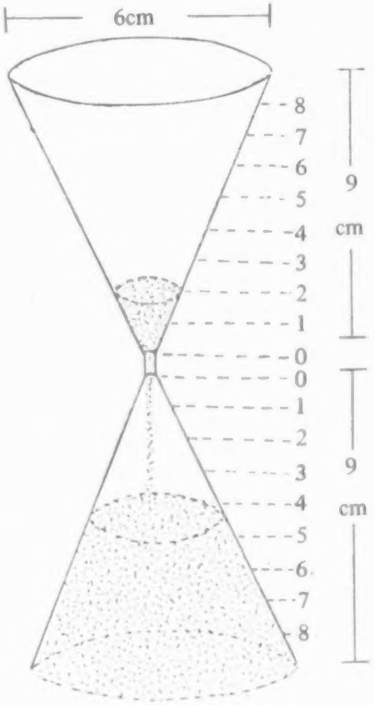
(1) How far will the train have travelled after 2.56 secs from the start?

(2) What time will be shown by the 8th time-marker?

<12> In a sand-timer, it takes 16 secs for 2 cm of sand to drop down.

(1) How long will it take 3 cm of sand to drop down?

(2) How many cm of sand will drop down in 2 mins 8 secs?



With respect to the different relations induced from multiple ratio $a \alpha b^{*} c$, an item is called of type I when a is a constant, type II when its unknown is a, and type III when its unknown is b or c. Type I items are concerned with inverse ratio, e.g. the walking item<5>, the motorcyling item<7> and the bicycling item<9(1)>. Type II items are concerned with a composition of two positive ratios, e.g. the lighting item <6(1)> and the heating item<8(1)>. Type III items are concerned with composition of a positive and an inverse ratio, e.g. the bicycling item <9(3)>, the lighting item <6(2)> and the heating item <8(2)>.

Table 1. Task analysis

Context	Variable	Relations •	Remark
Walking (catch up) <5>	s: distance t: time v: velocity	$V \alpha \frac{1}{t}$	. s is a constant which is given implicitely
Motorcycling (round trips) <7>	s,t,v	$T \alpha \frac{1}{v}$	. Percentage is used to describe the change of v. . The given s could be treated as a surplus information.
Bicycling (two size of bicycles) <9>	s,t,v r: radius of wheel n: number of rotations of wheel	(1) $R \alpha \frac{1}{n}$ (3) $V \alpha \frac{s}{n_1} : \frac{t}{n_2}$	. dynamic measurement . s and t are constant
Lighting <6>	p: power consumption n: number of electric bulb t: time	(1) $P \alpha nt$ (2) $T \alpha \frac{n}{p}$	. The changing rate of each variable is given.
Heating <8>	g: volume of gas w: volume of water t: temperature of water	(1) $G \alpha wt$ (2) $T \alpha \frac{g}{w}$	. The changing rate of each variabale must be found.
Recipe of Cake <10>	i: ingredient d: diameter of cake	(1) $I \alpha d^2$ (2) $D \alpha \sqrt{i}$ (4) comparison of D_1 & D_2, given two ingredients i_1 & i_2	. The answer is an irrational number
New Train Test <11>	$s, t, v_0=0$ a: acceleration	(1) $S \alpha t^2$ (2) $T \alpha \sqrt{s}$	. Constant acceleration is given.
Sand Timer <12>	h: height of sand left t: time	(1) $T \alpha h^3$ (2) $H \alpha \sqrt[3]{t}$	

• The unknown in each item is represented by capital letter.

IV. Understanding Levels

The method of analysis used on the data in order to obtain groups of items was an adaptation of the method used in the CSMS study (Hart, 1981, p. 7). Items had to satisfy the following criteria before they were considered to form a group:

(a) They should be of approximately the same level of difficulty i.e. have the same facility.

(b) The values of the homogeneity coefficient Φ item/item should be at an acceptable level.

(c) The items should be linked (Φ) with the items in both easier and more difficult groups.

(d) There should be some measure of mathematical coherence to these items.

(e) The groups should be scalable in the sense that a child's success (assessed as 2/3 correct) in a group entailed success in all easier groups (Error responses were not to exceed 7 per cent of the sample in any one test.).

(f) There should be no gross discrepancies when each age group's results were analysed in the same way.

To identify students at different levels of understanding, the criterion of the CSMS study (Hart, 1981, P.7) was also adopted. Students who did not succeed on 2/3 of the items of level $n+1$ but did succeed on 2/3 of the items of level k, for all $k<n+1$, are called level "n" students. A student who in this sense 'passes' a harder level of items without passing all easier levels is said to be an error sample.

The facility range of all 25 items in this study was between 18.8% ~ 95.7%. Two of these 25 items were rejected in forming groups because of their similarity with other items. The facilities of the rest of the 23 items which were used in forming groups is shown in Table 2.

Table 2. Facilities of items (N=1390).

success(%)	
95.7% | 92.6%	Four simple positive ratio items with non-integer rates, e.g. 3:5, 8:12, 12:8, 6:8 etc.
82.2%	Lighting question<6(1)>, Multiple ratio: Type Ⅱ (rates of change were given)
77.4%	Walking question<5>, Mulitple ratio: Type I
75.3%	Punch question<4(1)>, Continued ratio (demanding reduction of rate once)
72.9%	Bicycling question<9(1)>, Multiple ratio: Type I
67.3%	Punch question<4(2)>, continued ratio (demanding reduction of rate twice and enlargement of rate once)
65.6%	Heating question<8(1)>, Multiple ratio: Type Ⅱ (rates of change must be found)
64.0%	Lighting question<6(2)>, Multiple ratio: Type Ⅲ
59.8%	Heating question<8(2)>, Multiple ratio: Type Ⅲ
55.6%	Recipe of Cake Question<10(1)>, $y \alpha x^2$
55.4%	Motorcycling question<7>, Multiple ratio: Type I (demanding understanding of percentage)
50.3%	Recipe of cake question<10(2)>, $x \alpha \sqrt{y}$
47.6%	Recipe of cake questiion<10(3)>, $x \alpha \sqrt{y}$ (demanding operation on irrational number)
38.6%	New train test question<11(1)>, $y \alpha x^2$
38.6%	Recipe of soup question<3(2)>, comparison of rates
34.5%	Recipe of cake question<10(4)>, comparison of rates
31.0%	New train test question<11(2)>, $x \alpha \sqrt{y}$
28.6%	Bicycling question<9(3)>, Multiple ratio: Type Ⅲ (Variables were described in equation form)
23.2%	Sand Timer question<12(1)>, $y \alpha x^3$
18.9%	Sand Timer question<12(2)>, $x \alpha \sqrt[3]{y}$

Four out of the five "level four" items resulting from our previous study were simple positive ratio items and the other one was a continued ratio item. The facilities of these four simple positive ratio items were between 92.6% ~ 95.7%. They are grouped as 'level four' items in this study. The facility of the continued ratio item was 75.3% which was included in 'level five'. Three more groups of items which are beyond level four are formed by using the rest of the 19 items. The facility range for each group is shown in Table 3.

Table 3. Levels of understanding in ratio

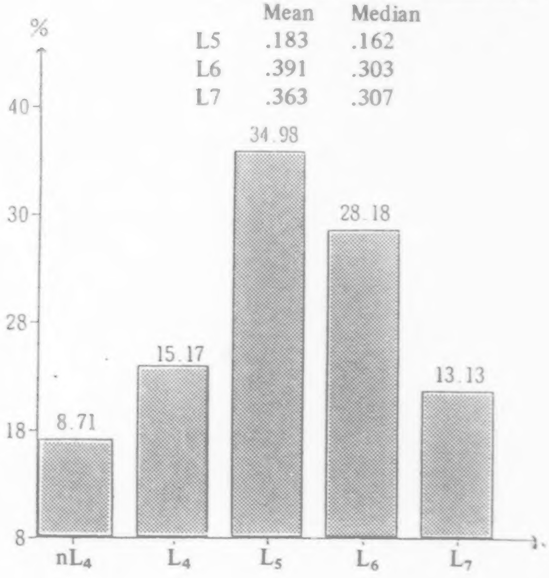
Level	Facility Range	Pass Mark
4	92.6~95.7%	3/4
5	67.3~82.2%	3/5
6	47.5~65.6%	5/7
7	18.8~38.6%	5/7

The frequency of students who achieved each level is shown in Table 4, where nL4 denote the group of students who did not achieve level four.

Table 4. Frequency of students who achieved each level
Total sample 1539; Valid sample 1478 (excluding error sample 3.45%)

Values of Φ coefficient in each level

	Mean	Median
L5	.183	.162
L6	.391	.303
L7	.363	.307



The description of levels comprised two components, i.e. mathematics structure and students' abilities.

The mathematics structure of the newly established levels 5 ~ 7 is shown in Table 5. Students' abilities of each level will be discussed in the next section.

Table 5. Mathematics structure of levels

Level	Mathematics Structure
5	. Relation between variables easy to recognize . Continued ratio (demanding reduction and enlargment of rates) . Multiple ratio: Type Ⅰ and Ⅱ . One step reasoning
6	. The changing rate of each variable must be found . Multiple ratio: Type Ⅰ ⊕ %, Type Ⅱ and Ⅲ . Non-linear ratio: $y \alpha x^2$ (awareness of the relation is by common sense) . One step reasoning
7	. Relations between variable are hard to recognize . Multiple ratio: Type Ⅲ (variable was described indirectly in equation form) . Non-linear ratio: $y \alpha x^3$ and $y \alpha x^2$ (awareness of the relation $y \alpha x^2$ demands a knowledge of physics) . Comparison of rates . Two step reasoning

V. Strategies Used by Students in Multiple Ratio and Non-linear Ratio

The correct strategies used by students in advanced proportional reasoning are classified according to three principles, namely

(1) Analogy of simple proportional reasoning strategies.
(2) Curtailment of reasoning process.
(3) Applying knowledge from natural science or advanced mathematics.

The incorrect answers are distinguished according to the following principles.

(1) Correct reasoning process with computation error.
(2) Degree of incompleteness in understanding ratio.
(3) Omission or misuse of information.
(4) Special errors with respect to the given context.

In this section, I shall briefly describe those strategies and errors, and present the percentage of students who used the strategy or made errors.

V-1 The Correct Strategies

(1) Analogy of simple proportional reasoning strategies

A multiple ratio is a composition of simple ratios. Many multiple proportional reasoning strategies used by students are the analogical strategies they used in simple proportional reasoning. For example, the formula method ($a_1 / b_1 = a_2 / b_2$ vs. $a_1 b_1 / c_1 = a_2 b_2 / c_2$), the multiplier method, the unitary method and building-up-using-halving were all used by students in multiple proportional reasoning.

These strategies were presented by students in either one integrated step or two separate steps. Some students could grasp the composite relation of the three variables in the item and use it to solve the item in one step. Some students repeated their simple proportional reasoning strategy twice by keeping one of the three variables fixed respectively. Their strategies included two steps.

(2) Curtailment of reasoning process

The curtailed structures of multiple ratios and non-linear ratios are relations such as $y \alpha 1/x$, $z \alpha xy$, $z \alpha x/y$, $y \alpha x^2$ and $y \alpha x^3$ respectively. Students who can grasp the corresponding relation with respect to the task and directly use it as their reasoning base could shorten their reasoning process. For example, the mathematics structure of the motorcycling task is $s=vt$. The given conditions were $s_1 = s_2 = 72$km, $v_2 = v_1 + 20\% v_1$, $t_1 = 115$ minutes and students were asked to find t_2. In general, students could use all given data to solve this task with a *step-by-step* strategy that includes three steps, namely

(i) finding $v_1 (= s_1 / t_1)$

(ii) finding $v_2 (= v_1 + 20\% v_1)$

and (iii) finding $t_2 (= s_2 / v_2)$

However, students who recognized the relation $t \alpha 1/v$, when s is a constant, and make their reasoning based on this relation, can skip step(i) and simplify step(ii). Such a strategy is more economic than the step-by-step strategy and is called a curtailed reasoning strategy.

The one-step strategies that were described in the above paragraph § V-1 (1) are examples of curtailed reasoning strategies.

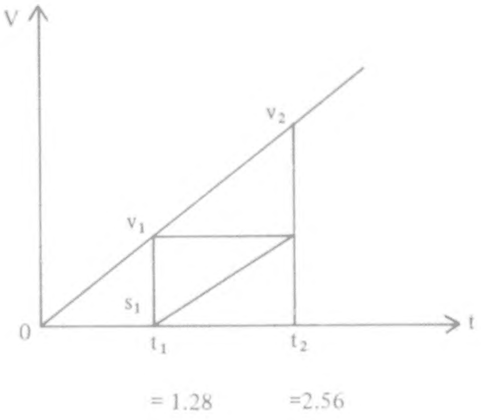
(3) Applying knowledge from natural science or advanced mathematics

The surface phenomenon of some tasks are physcial, e.g. the heating task, the lighting task and the new train test task. Besides the new train test task, the relations between the variables in the heating and lighting tasks could be derived from one's common sense, not necessarily from one's physics knowledge. However, some students did apply their physics knowledge, such as the heating formula H=mst, to solve the items.

In the interviews, some students applied their calculus knowledge to solve the new train test task, although calculus is not yet taught in their school mathematics. The new train test task is concerned with a constant acceleration movement with initial velocity $v_0 = 0$. The given conditions of the first item are $s_1 = 100$, $t_1 = 1.28$, $t_2 = 2.56$ and students were asked to find s_2.

Some students drew the v-t graph of the movement and transferred the problem of finding the distance of movement "s" to the problem of finding the area under the v-t graph. Two different procedures for finding s_2 were demonstrated by students in the interviews as follows.

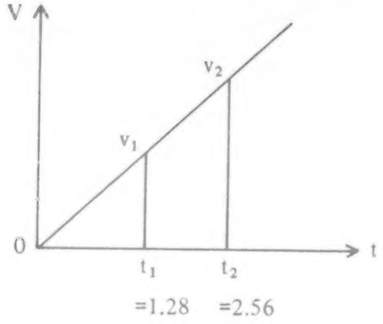
(i)



s_2 is the area of $\Delta ot_2 v_2$ and s_1 is the area of $\Delta ot_1 v_1$.

By dissecting $\Delta ot_2 v_2$ as shown in the figure, it is easy to see that the area of $\Delta ot_2 v_2$ is four times that of $\Delta ot_1 v_1$. Therefore, $s_2 = 400$ since $s_1 = 100$.

(ii)



$$\frac{s_2}{s_1} = \frac{\text{area}\,\triangle\, ot_2v_2}{\text{area}\,\triangle\, ot_1v_1} = \frac{(ot_2)^2}{(ot_1)^2} = \frac{4}{1}$$

$$s_2 = 4s_1 = 400$$

V-2 The Incorrect Answers

(1) Correct strategies with computation errors

For each correct strategy, there is a corresponding code to identify the students who used the strategy but made computation error(s).

(2) Degree of incompleteness in understanding ratios.

(a) Inverse ratio

With respect to the inverse ratio items, three different errors were distinguished.

(i) Mis-used positive proportion.

(ii) Using inverse proportion with wrong placement of some terms.

(iii) qualitative understanding of inverse ratio only. This indicates those students who only knew when one variable is increasing then the other variable is decreasing; however, they could not make the correct quantatative reasoning.

(b) Multiple ratio

With respect to multiple ratio types II & III items, four different errors were distinguished.

(i) Confusion over positive and inverse ratio.

(ii) Qualitative understanding of ratio only.

(iii) Can deal with only one of the two simple ratios in a multiple ratio.

(iv) Could deal with both simple ratios in a multiple ratio, but couldn't combine them correctly.

(c) Non-linear ratio

With respect to the non-linear ratio items, the errors students make could be easily distinguished in terms of which relations they used. For example, in the sand timer task, the relation between the height of the sand(h) and the time period(t) needed for the sand to drop down is cubic, i.e. $t \alpha h^3$. However, many relations such as $t \alpha 1/h$, $t \alpha 1/h^2$, $t \alpha h$, $t \alpha h^2$, $t \alpha h^4$, $t \alpha 2^h$ ... etc. were used by students. It is easy to code their errors by the relations they used. Analysis showed a strong correlation between students' understanding level and the kind of relation they used. The students who used a linear relation to solve this task had weaker reasoning ability than the students who used a quadratic relation. More precisely, in terms of levels of understanding, there are (65.9%, 49.7%, 17%, 2.1%) of students of level of understanding (4,5,6,7) respectively who mis-used the linear relation $t \alpha h$, and (6.3% 11.5% 32% 9.8%) of students of understanding level (4,5,6,7) respectively, who mis-used the quadratic relation $t \alpha h^2$ to solve the sand timer task.

(3) Omitted or misused information

(i) Extra-logical reasoning

Some students omitted the given data due to certain extra-logical reasons that occurred to them. For example, in the bicycling task, a father and his son were cycling with different sized bicycles. Students were asked to find the ratio between the father's and son's speed. Some students said that the father and his son went out together, the father always kept his speed to wait for his son, so the ratio of their speeds is 1:1.

(ii) Non-awareness that all variables are necessarily related

Some students were not aware that all three variables in a multiple ratio task are necessarily related. They might therefore ignore one of them and concentrate on the other two variables only. For example, in the lighting task, a student argued that as long as one connected the electric bulbs with power, then the power consumption had nothing to do with the number of bulbs. His reasoning was 'the more bulbs there are, the darker the bulbs will be'. Therefore, he concentrated only on the relation between power consumption and the time period of lighting.

(iii) Non-awareness that the given data was shared by all subitems

Two of the four sub-items in the cake recipe task asked students to find the size of cake that could be made when one kind of ingredient was restricted to a given amount. Some students said that with only one kind of ingredient it was not possible to make a cake.

(4) Particular errors within the context

(i) Miscopying a formula

In the physical phynomenon heating task, somestu dents tried but could not retrieve their physics knowledge, so they tried to construct a similar form of reasonable 'formula' to solve the task, e.g.

a. $G_1*W_1*T_1=G_2*W_2*T_2$
b. $T_2=(G_1/W_2)*(W_1/G_2)*T_1$
c. $(T_1+W_1)/G_1=(T_2+W_2)/G_2$
d. $W/G=T_0+T'$, T_0 denotes the initial temperature and T' denotes the temperature difference
... etc.

(ii) Finding time difference

To solve the round trip walking task, one has to fing the time difference from 7:05 Am to 7:25 Am and from 7:12 Am to 7:25 Am. It was quite a surprising that students made two kinds of errors on this computation. Namely,

a. 7 hours 25 minutes - 7 hours 5 minutes = 7 hours 20 minutes
b. 7 hours 25 minutes = 445 minutes
7 hours 12 minutes = 432 minutes

The ratio between the speed of two sisters was given as 1/432 : 1/445.

V-3 Frequency of Strategies

The following tables, Tables 6-8, show the frequency of strategies used and errors made by the 1390 students (excluding the students who did not achieve understanding level 4) in solving inverse ratio items, multiple ratio type II & III items and non-linear ratio items respectively.

Table 6. Frequency of strategies used in multiple proportional tasks (N=1390)(%)

Tasks (item number) Strategies		Lighting <6-(1)>	Lighting <6-(2)>	Heating <8-(1)>	Heating <8-(2)>	Bicycling <9-(3)>
Correct	Multiple Method (One-Step)	42.2	27.3	11.9	8.6	15.5
	Formulal Method	6.7	8.4	16.4	17.0	3.1
	Using Physics Formula	23.3	18.8	8.8	8.7	4.2
	Two-Steps Mutiplicative Strategies	0.1	0.6	11.6	8.6	4.1
	Step -by- Step	1.4	1.9	15.0	16.3	*
Incorrect	Computation Errors	2.37	1.51	8.78	6.48	1.15
	Simple Ratios Correct; Unable to Composite them	0.2	0.1	0.2	*	0.3
	Simple Ratio Incorrect	3.7	8.4	8.4	9.0	13.3
	Qulaitative understanding only	0.3	0.1	0.4	0.1	*
	Non-awareness of Qualitative Relation	0.4	*	0.1	0.1	10.0
	Ignored One Variable	2.6	5.3	2.7	4.7	9.6

Table 7. Frequency of strategies used in inverse proportional tasks (N=1390) (%)

	Tasks (item number) Stragegies	Walking <5>	Motorcycling <7>	Bicycling <9(1)>
Correct	Curtailed Reasoning Using Inverse Ratio	22.9	3.5	21.9
	Curtailed Reasoning Using Physics Formula	20.4	1.29	49.7
	Step-by-step	34.1	50.1	
	Others	•	0.1	•
Incorrect	Computation Error	4.2	15.3	1.2
	Mis-used Positive Ratio	5.3	1.9	3.3
	Wrong Placement of Some Variables	4.2	11.3	5.8
	Mis-used Information	1.6	3.9	5.5
	Unable Finding Time Difference	1.2	•	•
	Error in Understanding Percentagae	•	9.0	•
	Others	3.5	7.3	4.5

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Talbe 8. Frequency of strategies used in non-linear relation tasks (N=1390)

(%)

Tasks		Recipe of Cake			New Train Test		Sand Timer	
Item Number Strategies		10-1	10-2	10-3	11-1	11-2	12-1	12-2
Correct	Curtailed Reasoning Using Non-Linear Relation	23.60	29.42	28.13	7.98	3.60	7.19	8.35
	Curtailed Reasoning Using Appropriate Formula	31.08	19.64	18.71	21.51	17.27	3.60	1.87
	Step-by-step	0.07	0.29	0.29	8.13	9.64	12.16	8.13
	Advanced Maths Method	*	*	*	Interview Data		*	*
	Others	0.86	0.94	0.43	0.43	0.22	0.29	0.50
Incorrect	Computation Errors	1.08	3.39	4.32	12.01	12.59	3.31	5.04
	Misusing Quadratic Relation	0.43	0.57	0.71	0.29	0.14	16.55	15.25
	Using Other Relation	38.42	39.28	39.86	0	0	34.82	34.39
	Using Other Relations	1.58	1.29	1.15	0.29	1.58	1.87	1.58
	Misunderstanding Constant Acceleration Movement	*	*	*	29.20	24.60	*	*
	Nonawareness of Qualitative Relation	0	0	0	0.86	1.30	0.21	0.07
	Others	2.88	5.18	6.40	18.70	28.77	20.00	24.82

VI. Characterization of Advanced Proportional Understanding Levels

In order to present a picture of students in each advanced proportional understanding level, their abilities including their strengths, weaknesses and general proportional reasoning abilities will be discussed in this section.

VI-1 Strength

A good indicator of the strength of students' abilities in each understanding level is the use of an economical strategy. Table 9 shows the percentage of students at each understanding level who showed curtailed reasoning processes. The corresponding percentage of correct responses at each understanding level is also shown in brackets in each cell.

Table 9. Percentage of students in each understanding levels using curtailed reasoning process

Item	Strategy	L4 N=223	L5 N=513	L6 N=413	L7 N=193
Bicycling 9-(1)	curtailed reasoning by using inverse ratio relation	• 9.0 (29.2)	24.4 (76.4)	21.1 (83.8)	32.6 (90.2)
Lighting 6-(2)	curtailed reasoning by using complex multiplier method	8.5 (20.6)	22.6 (54.0)	38.0 (84.0)	50.3 (94.3)
Recipe of Cake 10-(1)	curtailed reasoning by using quadratic relation	3.1 (11.7)	7.2 (23.6)	36.1 (98.3)	60.1 (98.5)
10-(2)	curtailed reasoning by using square root	3.6 (8.1)	6.0 (13.8)	39.2 (95.4)	70.5 (97.4)
New Train Test 11-(1),11-(2)	curtailed reasoning using physics formula	4.9 (8.1)	16.8 (23.2)	34.4 (44.8)	74.1 (93.8)
Sand Clock 12-(1)	curtailed reasoning by using cubic relation	1.8 (4.1)	2.5 (9.6)	4.4 (18.6)	29.0 (84.0)
12-(2)	curtailed reasoning by using cubic root	2.7 (3.6)	2.5 (6.4)	5.0 (12.6)	34.7 (75.7)

• the number in brackets in each cell denotes the percentage of correct responses at that level of understanding.

Considering the percentage of students who showed curtailed reasoning processes, the following points can be observed from Table 9.

1. The higher the understanding level, the higher the percentage of students at that level using curtailed reasoning processes.
2. Very few students at understanding level 4 showed curtailed reasoning processes.
3. About 1/4 of the students at understanding level 5 used curtailed strategies in solving simple inverse ratio and multiple ratio problems, but very few of them used curtailed strategies in solving non-linear ratio
4. About 40% of students at understanding level 6 used curtailed strategies in solving complex ratio and quadratic relation problems, but very few of them used curtailed strategies in solving cubic relation problems.
5. About 1/3 of the students at understanding level 7 used curtailed strategies in solving cubic relation problems.

VI-2 Weaknesses

Certain errors made by students at each understanding level show several of their weaknesses. Tables 10 and 11 show the incidence of these difficulties. Table 10 shows the incidence of students' difficulties that are not directly related to proportional reasoning abilities.

Table 10. Incidence of weakness(%)

Item	Weakness	L4 N=223	L5 N=513	L6 N=413	L7 N=193
Walking <5>	unable to find time difference	4.5	1.0	0.2	0
Walking <5>	not aware of implicit information	12.1	4.3	0.5	0
Bicycling <9(1)>	confusion between perimeter and area	8.3	7.8	4.1	3.1
New Train Test <11-(1)>	difficulty with computation of decimals and irrational numbers	3.6	10.7	11.6	1.6
<11-(2)>		3.1	10.5	16.0	5.7
Bicycling <9-(1)>	using surplus information	13.5	3.9	2.2	0.5

The following points can be observed from Table 10.

1. About 10-16% of students at understanding levels 5 and 6 showed difficulty in computation with decimals and irrational numbers. Most level 4 students did not recognize the quadratic relation in the new train test task, so, they had no chance to show their computation abilities with decimals and irrational numbers.
2. Perimeter and area are confused by some students at each understanding level.
3. It is quite surprising that some students aged 16 and 17 could not find time differences.

The following table, Table 11, shows the incidence of students' difficulties that are directly related to proportional reasoning.

Some interesting points can be observed from Table 11.

1. When solving the 'every day' quadratic relation task, the cake recipe, most students at understanding level 4 and 5 applied an inappropriate linear relation. These students understand non-linear ratio qualitatively only. Students have to progress to level 6 and 7 before they can recognize the proper quadratic relation.
2. Concerning the cubic relation item (the sand timer) the percentage of students misusing a linear relation decreased sharply from lower level to higher level; the highest percentage misusing a quadratic relation was among level 6 students. It seems that students have to progress up to level 6 before they are likely to recognize that a 'non-linear' relation is the proper relation. A student who can recognize that the relation of variables in the sand timer task is non-linear, and who can also provide the proper cubic relation, is very likely a student of understanding level 7.
3. More than 20% of level 4 students and 10% of level 5 students have difficulty in reasoning with percentages. Since almost all students at levels 4 and 5 have no difficulty in reasoning with positive simple ratios, this shows that understanding percentage is not easier than understanding positive ratios.

Table 11. Incidence of proportional reasoning weakness(%)

Weakness	L4 n=223	L5 n=513	L6 N=413	L7 N=193
. Can't cope with the information: 'increasinging by 20%' <7>	22.4	10.5	3.6	2.2
. Merely qualitative understanding of inverse ratio <7>	13.5	6.3	2.3	1.6
. Unable to compose two positive ratios <6(1),8(1)>	11-20	4.5-12	2.6	0.5
. Unable to compose a positive ratio with an inverse ratio <6(2),8(2),9(3)>	11-15	11-12	5.1-8.5	1.0-3.6
. Unable to recognize that the three variables in multiple ratio tasks are mutually related <6,8,9>	7.6-9.4	4-7.8	0.7-1.7	0.0-
. Misusing a linear relation to solve a quadratic relation problem recipe of cake <10> new train test <11>	 79.8 56.1	 70.5 30.0	 3.9 13.1	 0.0 0.5
. Solving a cubic relation item,by misusing a linear relation <12> misusing a quadratic relation<12>	 65.9 6.3	 49.7 11.5	 17 32	 2.1 9.8

VI-3 Performance on Different Types of Ratio Task

The percentage of correct responses of students at each understanding level on the various mathematical types of ratio tasks as found by this study is shown in Table 12. These percentages can be viewed as indicating the general proportional reasoning abilities of students on different types of ratio tasks.

The data in the table 12 showed that a main criterion of advanced proportional understanding levels is the type of ratio that can be coped with.Roughly speaking, the types of ratio tasks that more than 2/3 of students in each understanding level can cope with can be shown in the right figure.

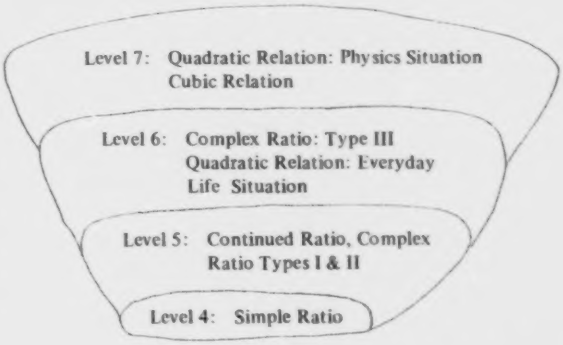
Level 7: Quadratic Relation: Physics Situation
Cubic Relation
Level 6: Complex Ratio: Type III
Quadratic Relation: Everyday Life Situation
Level 5: Continued Ratio, Complex Ratio Types I & II
Level 4: Simple Ratio

Table 12. Abilities of solving each types of ratio tasks(%)

Math Structure		Abilities	L4 N=223	L5 N=513	L6 N=413	L7 N=193
Simple Ratio x:y <1,2,3>*		.Can apply correct multiplicative strategies to solve simple ratio items with arbitrary rate.	90	93	96	98
Continued Ratio x:y and z:y <4>		.Can apply 'extension/reducing' method to find the relation of two variables via a medium.				
		.. Applying the method once	25	87.3	85	90.7
		.. Applying the method twice	13.5	78.4	79.2	81.9
Complex Ratio	Type I $Y \alpha 1/x$ <5,9(1)>	.Can recognize the inverse ratio relation and apply correct multiplicative strategies to it.	29.2 | 35.0	76.4 | 78.0	83.8 | 91.8	90.2 | 97.4
	Type II $Z \alpha xy$ <6(1), 8(1)>	.Can compose two simple positive ratios by multiplicative strategies	34 | 49	64 | 86	87.2 | 95	98 | 99.9
	Type III $Z \alpha x/y$ <6(2),8(2) 9(3)>	.Can compose a positive ratio with an inverse ratio.	19.3 | 22.5	51 | 56	85 | 92	93 | 96
Non-Linear	$Y \alpha x^2$ <10>	.Can recognize the quadratic relation of an everyday life situation	12.1	25.1	98.8	99.5
	<11>	.Can recognize the relation between distance and time in constant acceleration movement	11.7	33.9	56.4	95.3
	$Y \alpha x^3$ <12>	.Can recognize that a non-linear relatiion is necessary and can derive a proper relation	5.9	13.5	23	86

VI-4 Characterization

To summarize, I will describe the characteristics of students in each understanding level as derived from the data as follows.

1. Level 4
   (1) Able to apply correct multiplicative strategies, such as multiplier/unitary/formula methods to solve simple ratio tasks with arbitrary rate.
   (2) Unable to use curtailed reasoning processes on complex ratio items and non-linear relation items.
   (3) Weak at recognizing implicit information and at distinguishing surplus information.
   (4) May have difficulty understanding the meaning of increasing by 'n%'.
2. Level 5
   (1) Able to apply correct multiplicative strategies to solve simple ratio, continued ratio, inverse ratio and composition of two simple ratio items.
   (2) Might have difficulty in composing a positive ratio with an inverse ratio.
   (3) May have difficulty in recognizing a non-linear relation.
   (4) Have strong tendency of using linear relation to solve non-linear relation item.

It seems that students of level 5 still have not developed their ability of recognizing non-linear relation yet.

3. Level 6
   (1) Able to apply multiplicative strategies to solve simple ratio, complex ratio and quadratic relation with everyday life situation items.
   (2) Could aware the necessity of non-linear relations.
   (3) Have difficulty in applying proper relation to solve cubic relation items.
   (4) Might affected by complicated computation, e.g., decimals and irrational numbers, while they were reasoning proportionally.
4. Level 7
   (1) Able to solve complex ratio and non-linear relation items.
   (2) Not only can recognize the necessity of non-linear relation but can also derive a proper relation.
   (3) Proportional reasoning processes are not affected by the context and complicated number structure within tasks.

VII. Summary

1. Previously, we constructed four linearly-ordered levels of understanding simple ratio (Lin, 1987,1989) applicable to junior high school students. Using senior high school students, in this study we built up three higher levels of understanding ratio beyond the four levels of understanding simple ratio. This structure of seven levels of understanding ratio is internally consistant. This was tested while the new higher understanding levels were being constructed.
2. Both number structure and context, particularly number structure, affect junior high school students' performance on simple ratio tasks (Lin, 1989; Tourniaire & Pulos, 1985). This study found that number structure in advanced proportional tasks is not an important factor affecting senior high school students' performance. However, the context, e.g. everyday life situation v.s. physics situation, can still play an important role in senior high school students' advanced proportional reasoning (c.f. Table 11, item 10 & 11), particularly on non-linear relation tasks.
3. Among senior high school students aged 16 and 17 in Taiwan, about 3/4 of them achieved understanding level 5, about 2/5 achieved understanding level 6, and about 1/7 achieved understanding level 7.
4. As far as Taiwan senior high school students are concerned, this study found that different types of ratio tasks could be ordered from easy to difficult as follows:
   simple positive ratio
   < continued ratio, inverse ratio, complex ratio: type II
   < complex ratio, type III
   < quadratic relation: everyday life situation
   < quadratic relation: physics situation
   < cubic relation
   Notation '<' should be read as 'is easier than'.
5. The more economic strategies were not widely used by Taiwan senior high school students.
6. The ability to recognize the necessity of a non-linear relation was not shown by the majority of Taiwan senior high school students. Indeed, more than 70% of the sample in this study did not show this ability.
7. Computing time differences and distinguishing perimeter from area are supposed to be elementary abilities. Some senior high school students still showed difficulty with this.
8. The bicycling task was adapted from some popular exercise material used by almost every junior high school in Taiwan. This study found that only 29% of first and second graders in senior high school could cope with this task. This indicates that the

mathematics material used in junior high school may be too difficult for many students at that level.

References

Hart, K.M. (ed)(1981). *Children's understanding of mathematics: 11-16*, John Murray.

Lin, F.L. (1987). Describing level of understanding: ratio, *Proceedings of P.M.E.-XI, II*, 416-423.

Lin, F.L. (1988a). Societal difference and their influences on children's mathematics understanding, *educational Studies in Mathematics, 19*, 471-497.

Lin, F.L. (1988b). Beyond ratio formula, *Proceeding of P.M.E.-XII, 1*, 320-325.

Lin, F.L. (1990a). *Domains of reasearch in deep understanding of ratio and advanced proportional reasoning*, A first year report of the research project "Understanding in the deep structure of ratio", Dept.of Math. National Taiwan Normal University (in Chinese).

Lin, F.L. (1990b). *Senior high school students' understanding in multiple ratio and non-linear ratio*, A second year report of the research project "Understanding in the deep structure of ratio", Dept. of Math. National Taiwan Normal University (in Chinese).

Tourniaire, F.& Pulos, S. (1985). Proportional reasoning: A review of the literature, *Educational Studies in Mathematics, 16*, 181-204.

Usiskin Z. (1987). *The real true understanding of mathematics*, paper presented at Fifth Annual Hellman Lecture, Long Island University, Jan. 28.

Yang, J.S. (1988). *Survey study on senior high school students' understanding of basic science*, Science Education Center, Taiwan Normal University (in Chinese).

複比與非線型比的了解

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摘要

調查國中生的比例推理能力時，曾建構了解單比例推理的四個了解層次。本文主要描述超越這四個了解層次的三個高等比例推理的了解層次。調查對象是具代表性的台灣高中一、二年級學生共1539 名，選擇的概念領域包括複比與非線型比。調查方法以筆測爲主，訪談爲輔。

高等比例推理的三個了解層次中的學生特徵，包括各層次學生有能力處理的不同型態之比例問題，解題的策略，解題時簡捷的想法，解題時易犯的錯誤，與較弱的能力等等，都是本文探討的重點。

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A Design for Implementing Mastery Learning on Sublimation, A Chemistry Experimental Technique

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ABSTRACT

Chemistry research supervisors are often frustrated by the fact that students are not well equipped with the necessary laboratory techniques at the start of their research programs. The purpose of this study is to design a method of implementing mastery learning of the sublimation technique to develop students' ability in performing it correctly, as well as using the technique to solve chemistry problems they will encounter later, in other words, achieving transfer of learning. Instructional materials and strategies were developed and organized to bring the students up to three successively higher learning levels: concrete, identity, and classificatory. The instruction was assessed by the degree of learning progress, which in turn was evaluated by positive correlations between two consecutive tests, between task performance and test results, and among the results of a set of laboratory assignments. Progress of learning was observed in the rightward shifts of the S-curves and the downward shifts of the P-curves during a set of assignments. CP_j values of all items were less than 0.44. In the plots of P_j vs. CP_j all items were in upper left quadrant. These results indicate that all items were of good quality. An acceptably small degree of anomalous item patterns reflected unambiguous instruction. In each post-test 2 for the three levels all the CS_i values for individual students were less than 0.50, and all the three D^* values were less than 0.4022. Small CS_i and D^* values indicate an acceptably small degree of learning difficulties and erratic studies (careless mistakes, copying or guessing responses) after instruction. Those students (100% for both the concrete and the identity levels, and 95.6% for the classificatory level) with high scores in the paper-pencil test indeed obtained high yield and high purity. These facts were consistent with the learning gain shown in individual performance profiles. Once the students mastered the technique, they kept the ability. The progress of learning observed as discussed above indicated the effectiveness of our implementation method for mastery learning of sublimation technique. These instructional materials and strategies were satisfactory for the college introductory organic chemistry laboratory course. The methodology used in this study can be extended advantageously to the study of instruction on other chemistry experimental techniques.

Key words: implementing mastery learning, chemistry laboratory technique, criterion-referenced mastery measurement, instruction, sublimation, item-response table, S-P chart analysis

I. Introduction

There have been a considerable number of works in the field of improving laboratory teaching, but only a few have addressed college laboratory instruction (Tamir, 1989). Teachers often give their students laboratory assignments simply taken from commercial textbooks, however, they do not really consider the design of instructional strategies. The instructional strategies should include selecting the sequence of the assignments and assessing how much and how well certain specified contents of the experimental techniques have been assimilated into the learners' cognitive structures. Current teachers' assessments on students' chemistry experimental techniques are mainly based on the impression grading during the experiments and on the degree of the students' success, if available, at the end of the experiments. The weak points of assessments of this type are the following: (1) Teachers provide only their "impressions" of success. (2)The assessments can not find out what mistakes the learners have made and therefore remedial instructions can not be made. (3)At best, students perform as instructed, but one can not predict whether the learning can be transferred into a new situation. Therefore, the chemistry research supervisors are often frustrated by the fact that the students are not well equipped with the necessary laboratory techniques at the start of their research programs.

Johnstone and Wham (1982) stated that the inquiry-oriented laboratory investigations require that the students simultaneously apply the functional knowledge of the subject matter (e.g., vapor pressure), proficiency in the laboratory techniques (e.g., sublimation), and intellectual inquiry skills (e.g., generalization). These demands put a heavy burden on the students. Tamir (1989) suggested that this overload can be decreased by providing the students with opportunities to gain the basic commands of each component before the students have to apply all of them simultaneously. It is generally agreed that each laboratory technique consists of particular part-skills and should have sufficient content to establish students' ability. The instructional materials already exist. How the students learn and apply the materials to solve the chemistry problems is what is important. Sublimation, one of the experimental techniques in chemistry, is a multiple task that has critical attributes and belongs to the class "process concepts" (Herron, 1977). A multiple task is one that has a number of possible inputs. The task is performed accordingly depending on the input. After performing only one assignment, the students can merely acquire the initial learning. A rational set of successive follow-up assignments should be given to students to master a multiple task (Klausmeier, 1980; Dumas-Carre and Larcher, 1987). The organization of the elements of the instructional materials has long been an important issue in educational planning, but minimal information is available for describing the organizational process. This study is to design a method of instructing mastery learning of the sublimation technique. The method is to develop students' ability to perform correctly and use the technique to solve new chemistry problems, in other words, to achieve transfer of learning. Reported here are how the instruction materials and the rational set of laboratory activities were selected and organized, how the instruction procedure was developed, and how the students' achievements were assessed.

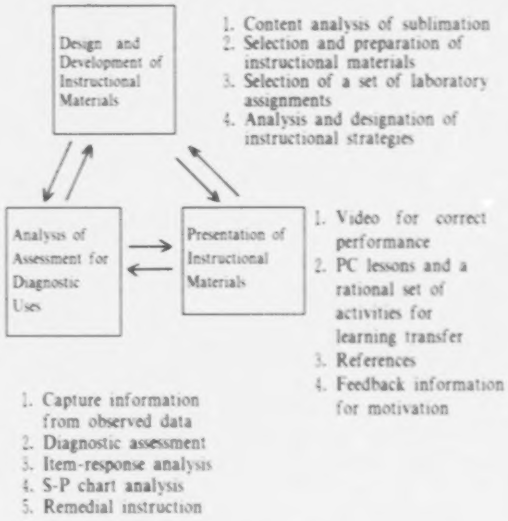
Design and Development of Instructional Materials
1. Content analysis of sublimation
2. Selection and preparation of instructional materials
3. Selection of a set of laboratory assignments
4. Analysis and designation of instructional strategies
Analysis of Assessment for Diagnostic Uses
Presentation of Instructional Materials
1. Video for correct performance
2. PC lessons and a rational set of activities for learning transfer
3. References
4. Feedback information for motivation
1. Capture information from observed data
2. Diagnostic assessment
3. Item-response analysis
4. S-P chart analysis
5. Remedial instruction

Fig. 1. The three-phase cycle of educational activities

II. Methods

A three-phase cycle of educational activities was used to develop the instructional design (Fig. 1).

Subjects: The subjects for this study included 23 sophomores in Department of Chemistry, National Taiwan Normal University.

Instruments: The instruments for criterion-referenced mastery measurements (CRMM) of the sublimation technique were constructed and validated on the basis of specific assessment criteria (Wang and Horng, 1991). CRMM were used here as an aid and the driving force of learning. CRMM were the means of keeping instruction consistent with job requirements and they clearly distinguished whether or how well the students could perform. Paper-pencil tests took the form of multiple-choice items; test items measured the students' attainment of the sublimation technique at the specific learning level; each item was specific for a part-skill. Each paper-pencil test consisted of three categories of items. The first category evaluated student's "recognition-repetition" ability for the concrete level. The second category evaluated the "identification-reproduction" ability for the identity level. And the third category evaluated "generalization to all ordinary cases" for the classificatory level. For each level, equivalent test items were used for pre-test, post-test 1, and post-test 2 as described in the discussion section below.

Assessment procedure: Paper-pencil tests were administered in three phases. A pre-test was conducted before the first assignment to find out what the students already knew. Post-test 1 was given after the first assignment. Post-test 2 was carried out immediately after a rational set of representative activities. Clinical interviews were conducted by the teacher on those students who showed anomalous student patterns in the S-P chart analysis to find out their learning difficulties. The procedure designed by us (Wang *et al.*, 1991) was used to diagnose the learning difficulties and to monitor the learning progress of individual students. The computer program written by us (Wang, 1990) quickly and effectively provided the I-R (item-response) tables and the S-P (student-problem) charts, from which the necessary information was obtained. Anomalous item patterns reflected ambiguity in instruction. Anomalous student patterns indicated insufficient preparation of prerequisite skills or erratic studies. The teacher identified individual student's strengths and weaknesses. The latter includes careless mistakes and copying or guessing responses. These anomalous patterns were quantified by caution index CP_j for j-th item and the caution index CS_i for i-th student. The heterogeneity of the S-curve and the P-curve was expressed by D^*, the disparity coefficient. Passing rate of item j (P_j) is the number of students who answered right divided by the total number of the students. Increased passing rate of an item after instruction showed sensitivity of learning gain. The progress of learning was expected in positive correlations (1) between the results of pre-test vs. post-test 1 and post-test 1 vs. post-test 2 using the I-R tables and the S-P charts, (2) between the task performance predicted from the test result and the task performance attained, and (3) among the results of the rational set of assignments.

Instructional materials: The contents and the learning outcomes included in the assignments were based on leading textbooks (Roberts *et al.*, 1985; Cheronis and Entrikin, 1963; Williamson, 1987; Fieser and Williamson, 1987; and others). The instructional materials were developed based on specific instructional and assessment criteria that arose from content analysis [structural task analysis (Gagné, 1987), hierarchical concept mapping (Novak and Gowin, 1984), and process concept analysis], and instruction analysis (Klausmeier, 1980; Dumas-Carré and Larcher, 1987). These analyses were made by the authors and checked by three chemistry teaching assistants and three professors. The analyses pointed out what and how the students must do and why they must so perform. Content analysis also identified the connection of sublimation to its coordinates, to discriminate the former from the latter. Content analysis further identified the prerequisite skills to prepare the students to learn the technique. A set of laboratory assignments was selected to lead the students to higher learning attainment levels, i.e., concrete, identity, and classificatory levels proposed by us (Wang and Horng, 1991) based on the CLD theory (Klausmeier, 1980) and the step-by-step learning model (Dumas-Carré and Larcher, 1987). A set of laboratory assignments that would lead students to the target learning levels was selected from the content analysis. The video and recitation materials for the laboratory instruction were prepared to ascertain whether the students could learn the correct techniques and accurately perform the part-skills. The process-concept (PC) lessons were prepared to instruct students to perform a rational set of experiments. These PC lessons were to ascertain whether or not the students have acquired conceptual level learning of the techniques. The instructional materials designed for sublimation were tested and modified through micro-teaching.

Instruction strategies: In the instruction of laboratory techniques, an instructional analysis was conducted to identify the instructional materials. The materials would help the students attain target laboratory techniques to the expected learning levels. The classificatory level is the highest expectable for second year college students. In the analysis, the main variables considered were the characteristics of the students, the level of the technique to be attained, the instructional media and the assignments to be used, and the extent of guidance to be provided. The teaching materials were broken into small modules for each part-skill to strongly bond the students to the teacher. Fig. 2 shows the instruction mode vs. learning mode used in the mastery learning of sublimation. At the concrete level, the teacher gave an overt presentation with programmed instructions using the video and recitation instruction media. As the attainment level went higher, the presentation shifted gradually from overt to covert. As the attainment level went higher, the style changed to the guided discovery using a rational set of assignments. The left end of the "presentation" axis in Fig. 2 represents the concrete level where the teacher presented detailed accounts of the sublimation technique using the materials mentioned above. Towards the right end of the "presentation" axis, the teacher intentionally instructed less and less

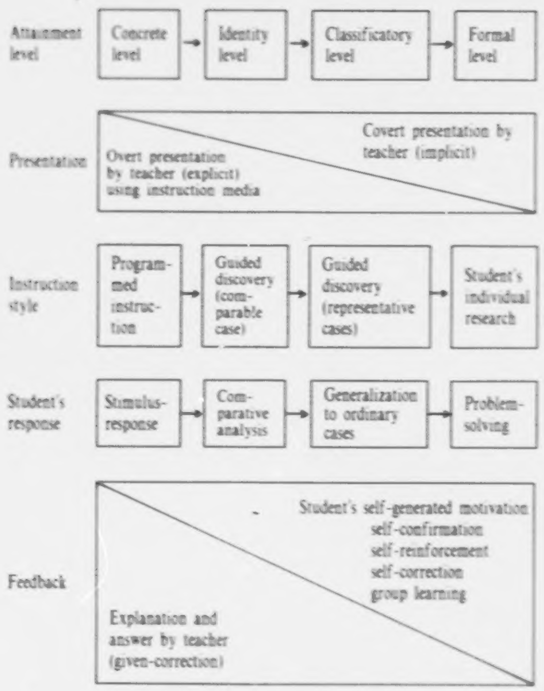
Attainment level
Concrete level
Identity level
Classificatory level
Formal level
Presentation
Covert presentation by teacher (implicit)
Overt presentation by teacher (explicit) using instruction media
Instruction style
Programmed instruction
Guided discovery (comparable case)
Guided discovery (representative cases)
Student's individual research
Student's response
Stimulus-response
Comparative analysis
Generalization to ordinary cases
Problem-solving
Feedback
Student's self-generated motivation
self-confirmation
self-reinforcement
self-correction
group learning
Explanation and answer by teacher (given-correction)

Fig. 2. Instruction/learning modes in mastery learning of sublimation.

to enhance the students' thinking power. The left end of the "response" axis is where the students were instructed to react quickly to the stimulus (item) during the teacher's presentation. From the feedback information, the students would come to the right answer to an item and use the information for correction and confirmation. Through a rational set of representative laboratory assignments, the students were encouraged to recognize critical attributes and to search for variable attributes of sublimation and thus led to progressive generalization. Towards the right end of the "feedback" axis, the students increased the weight of their role in self-learning (self-confirmation, etc.). The students marked their answers against the correct answers given by the teacher or answers given by other students for self-correction and self-confirmation. I-R charts were then converted to S-P charts for further analyses. The effectiveness of the instruction design was confirmed by the high degree of agreement between the test results and the task performances as shown in the discussion section.

III. Results and Discussion

Sublimation is a technique for purifying a solid. The solid is vaporized at a temperature lower than its melting point. The vapor is condensed to form pure crystals on a cold surface. Sublimation may be performed under atmospheric or reduced pressure. The coolant may be gas, liquid or solid. Sublimation is particularly useful for purifying solids in small scale because there is little loss of material in transfer. It is preferred over recrystallization when the material to be purified weighs less than 100 mg.

The progress of learning was expected in three positive correlations. The first is between the results of the pre-test vs. the post-test 1, and the post-test 1 vs. the post-test 2, using the I-R tables and the S-P charts analyses. The second is between the task performances predicted from the test results and the task performances attained. The third is among the results of the rational set of assignments. The first two correlations are discussed as follws.

A. The concrete level

Students at this level should be able to perform correctly the technique on a typical sample. They also should develop the ability of "recognition-repetition", with which they are to recognize that the specific situation has been studied and that the operations can be repeated as instructed. As for the sublimation technique, the student should be able to perform correctly the sublimation of impure solids such as naphthalene under atmospheric pressure using ice water as a coolant. Whether the students had really attained the concrete level of learning was evaluated by the test items that could evaluate the students' ability to perform correctly. I-R tables and S-P charts were constructed from the results of these tests and are analyzed in the following paragraphs.

1. The I-R table analysis

Consistency of learning gain of individuals at the concrete level is observed in the I-R table (Table 1) by the responses to each item, where "1" denotes right and "0" wrong. The consistency of learning gain means that the denoting numbers, 1 and 0, increase or stay the same, respectively, in the three successive tests. Each row showed a student's performance for each item on pre-test, post-test 1, and post-test 2. Each column showed the pattern of the class responses for each item.

2. The S-P chart analysis

The rightward shift of the S-curve as a whole in the three S-P charts represents the consistency and the uniformity of the learning gain, showing that the instruction was efficient. The occurrence of the rightward shift is observed in comparison of the results of the paper-pencil tests: (a) the pre-test (Chart 1) vs. the post-test 1 (Chart 2), and (b) the post-test 1 vs. the post-test 2 (Chart 3). The progress of learning

Table 1. Item-response[a] chart for sublimation - concrete level

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Test[b]	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123
Student No.																				
1	111	111	111	111	111	111	111	111	011	111	111	111	111	111	111	111	000	011	111	111
2	111	111	000	111	111	111	011	011	011	111	111	011	111	111	000	111	000	111	111	111
3	111	011	011	011	011	011	111	011	111	011	111	011	111	011	111	111	011	111	111	011
4	111	111	001	011	011	111	111	011	111	111	111	111	111	001	011	111	111	111	111	011
5	111	111	000	111	011	111	111	011	111	011	111	111	111	001	111	111	111	111	001	011
6	111	111	001	111	011	111	111	011	111	111	111	111	111	111	011	111	011	111	111	111
7	111	011	000	011	111	111	011	011	111	011	000	111	111	111	011	111	011	111	111	111
8	111	111	001	111	111	011	111	011	111	111	111	111	111	111	011	111	011	111	111	111
9	111	111	000	111	111	111	011	011	011	111	000	111	111	111	000	111	111	111	111	111
10	111	011	001	111	111	111	111	011	011	111	111	111	111	111	111	111	111	011	111	111
11	111	011	010	000	011	111	111	011	011	011	111	111	111	011	000	111	000	111	111	001
12	011	011	111	111	011	111	011	011	011	111	111	111	111	111	111	111	000	011	111	001
13	111	011	111	111	011	111	011	011	111	111	001	111	111	111	111	111	011	111	111	011
14	111	011	110	111	111	111	001	011	111	111	000	111	111	111	111	111	000	011	111	001
15	111	011	111	000	111	111	011	011	111	111	000	111	111	111	011	111	011	111	111	111
16	111	011	101	111	111	111	011	011	111	111	111	111	111	111	111	111	011	111	111	111
17	111	111	111	001	111	111	011	011	111	111	111	111	111	111	111	111	111	111	111	111
18	111	111	000	000	011	111	011	011	111	111	111	111	111	111	011	111	000	011	111	111
19	111	111	001	001	111	111	011	011	011	111	111	111	111	111	011	111	001	111	111	111
20	111	111	111	001	011	111	111	011	111	111	111	111	111	111	111	111	111	111	111	111
21	001	111	000	000	111	111	011	011	111	111	111	111	111	111	111	111	011	111	111	111
22	111	111	111	000	111	111	011	011	011	111	000	111	111	111	111	111	111	111	111	111
23	111	111	000	000	011	111	011	111	011	011	111	111	111	111	111	111	111	111	111	111

[a] Response: 1 denotes right; 0 denotes wrong.

[b] Test 1: pre-test; Test 2: post-test 1; Test 3: post-test 2.

was also observed from two more pieces of evidence. (c) All the CS_i values in the post-test 2 are less than 0.36, meaning that all the students did well. (d) D^* decreased from 0.5729 (Chart 1) to 0.5375 (Chart 2) and finally to 0.4022 (Chart 3), also showing the sensitivity to learning gain. These facts indicated that the instruction strategies were of good quality.

The downward shift of the P-curve as a whole in the three S-P charts represented the sensitivity and the uniformity of the learning gain, and showed that the instruction was efficient. The occurrence of a downward shift was observed by comparing the results of the paper-pencil tests: (a) the pre-test (Chart 1) vs. the post-test 1 (Chart 2) and (b) the post-test 1 vs. the post-test 2 (Chart 3). The progress of learning was also observed from three more pieces of evidence: (c) P_j for every item increased from pre-test to post-test 1 to post-test 2 as in P_j for item 8, which increased from 13% to 91% to 100%, showing sensitivity to learning gain. (d) All the CP_j values in the post-test 2 were less than 0.44, meaning that all the items were good ($CP_j < 0.50$) (Sato, 1980). (e) In the plot of P_j vs. CP_j, all items were in the upper left quadrant, meaning that they were of good quality (Sato, 1980).

3. Correlation between the results of the tests and of the task performances

For sublimation the yield and the purity of the product are the results of the task performances. Those students (95.6%) who obtained good experimental results of high yield and high purity also did well in post-test 1. The positive correlation between the results of the tests and those of the task performances further

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Chart 1. S-P chart for sublimation - concrete level (pre-test)

PROBLEM NUMBER D*-0.5729

	13	16	19	12	06	01	14	10	11	18	20	02	09	05	15	04	03	07	17	08	C.A.	%	CS_i
STUDENT	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
20	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	18	90	0.63
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	17	85	0.11
1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	17	85	0.73
16	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	16	80	0.12
6	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	0	0	15	75	0.15
21	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	15	75	0.29
8	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	15	75	0.37
22	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	15	75	0.37
10	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	0	15	75	0.47
13	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	0	0	14	70	0.22
9	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	0	0	1	0	14	70	0.32
23	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	0	0	0	1	1	14	70	0.51
19	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	13	65	0.02
15	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	0	1	0	0	0	13	65	0.20
2	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	13	65	0.25
4	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	0	0	1	1	0	13	65	0.41
14	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	13	65	0.43
5	1	1	0	1	1	1	0	0	1	1	0	1	1	0	1	1	0	1	1	0	13	65	0.78
18	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	12	60	0.08
7	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	0	0	0	0	0	11	55	0.19
12	1	1	1	1	1	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	11	55	0.44
11	1	1	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	9	45	0.22
3	1	1	1	0	0	1	0	0	1	1	0	0	1	0	1	0	0	1	0	0	9	45	0.56
C.A.	23	23	22	21	21	21	19	18	18	18	16	14	14	13	13	11	10	09	08	03			
P_j(%)	100	100	95	91	91	91	82	78	78	78	69	60	60	56	56	47	43	39	34	13			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CP_j	.00	.00	.85	.42	.63	.85	.27	.24	.84	.97	.22	.36	.88	.55	.55	.73	.39	.96	.48	.27			

C.A. : Number of correct answer.
— : S-Curve ; ..... : P-Curve.

confirmed the efficiency of the instruction. Those students who failed in the first experimental assignment were required to repeat the same task after remedial instruction before they took up the second assignment.

B. The identity level

The ability at this level is "identification-reproduction". The student must reproduce the procedures that are performed in the concrete level for a comparable case. For the sublimation technique, the student can select the appropriate apparatus and successfully perform sublimation on a solid such as camphor under atmospheric pressure using water as coolant, which is comparable to the procedure in the concrete level. The test items used here could evaluate the students' ability in making comparative analysis of the new situation against the task performed in the concrete level.

1. The I-R table analysis

Consistency of learning gain of individuals at the identity level was observed in the responses displayed for each test item in the I-R table (not shown).

2. The S-P chart analysis

The consistency and the uniformity of the learning gain at the identity level was observed in the S-curve of the three S-P charts (not shown). The progress of learning was also observed from D* that decreased from 0.2181 (pre-test) to 0.1677 (post-test 1) and finally to 0.0000 (post-test 2). All the CS_i values of the post-test 2 were 0.00, meaning that all the students did well. These facts indicated that the instruction materials were of good quality and led the students to the identity level.

The sensitivity and the uniformity of the learning gain for the identity level were again observed in the downward shift of the P-curves in the three S-P

Chart 2. S-P chart for sublimation - concrete level (post-test 1)

PROBLEM NUMBER D*=0.5375

STUDENT	02	05	06	09	12	13	16	18	07	10	19	01	08	14	20	15	11	17	04	03	C.A.	%	CS_i
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19	95	0.43
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19	95	0.43
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	19	95	0.60
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	19	95	0.69
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18	90	0.00
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	18	90	0.16
4	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	18	90	0.38
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	18	90	0.44
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	18	90	0.44
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	17	85	0.00
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	17	85	0.00
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	17	85	0.26
21	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	17	85	0.26
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	17	85	0.31
12	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	17	85	0.80
5	1	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	0	16	80	0.69
14	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	0	1	1	16	80	0.73
11	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	15	75	0.56
C.A.	23	23	23	23	23	23	23	23	22	22	22	22	21	21	20	20	17	16	14	09			
P_j(%)	100	100	100	100	100	100	100	100	95	95	95	95	91	91	86	86	73	69	60	39			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
CP_j	.00	.00	.00	.00	.00	.00	.00	.00	.35	.35	.35	.70	.21	.64	.15	.30	.89	.30	.78	1.04			

C.A. : Number of correct answer.
— : S-Curve ; ... : P-Curve.

charts by comparing the results of the paper-pencil tests. The progress of learning was further observed from three more pieces of evidence: (a) P_j for every item increased from the pre-test to the post-test 1 to the post-test 2 as in P_j for item 2, which increased from 26% to 78% to 91%. (b) All the CP_j values of the post-test 2 were 0.00, meaning that they were good. (c) In the plot of P_j vs. CP_j, all items were in the upper left quadrant, meaning that they were of good quality.

3. Correlation between the results of the tests and of the task performances

Those students who obtained good experimental results (100%) of high yield and high purity also did well in post-test 2.

C. The classificatory level

The ability of a student in this level is "generalization to all ordinary cases". For the sublimation technique, the student can successfully perform on a rational set of ordinary impure solids, such as p-dichlorobenzene, hexachloroethane, anthraquinone, caffeine, *p*-benzoquinone, and 1-naphthol. The task includes successfully using various sublimation apparatuses and determining the sublimation temperature and pressure. The test items used here could evaluate the students' ability in making generalizations from various attributes of the assignment and in giving accurate judgment on new situations.

1. The I-R table analysis

The consistency of learning gain of individuals at the classificatory level was observed with the responses to each test item in the I-R chart (not shown).

2. The S-P chart analysis

The rightward shift of the S-curve as a whole in the three S-P charts represented the consistency and the uniformity of the learning gain at the classificatory level, showing that the instruction was efficient. The progress of the learning was observed from two more

Chart 3. S-P chart for sublimation - concrete level (post-test 2)

PROBLEM NUMBER D*=0.4022

STUDENT	01	02	05	06	07	08	09	10	12	13	14	16	18	19	20	15	11	04	17	03	C.A.	%	CS_i
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100	0.00
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	19	95	0.00
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19	95	0.35
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19	95	0.35
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	18	90	0.00
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	18	90	0.00
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	18	90	0.14
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	18	90	0.36
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	18	90	0.36
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	17	85	0.00
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	17	85	0.00
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	17	85	0.10
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	17	85	0.20
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	17	85	0.31
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	16	80	0.08
C.A.	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	20	18	16	16	13			
P_j(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	86	78	69	69	56			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CP_j	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.44	.26	.26	.07			

C.A. : Number of correct answer.
— : S-Curve ; _ : P-Curve

pieces of evidence. (a) All the CS_i values in the post-test 2 were less than 0.34, meaning that all the students did well. (b) D* decreased from 0.3903 to 0.3869 and finally to 0.2364, also showing the sensitivity to learning gain. These facts indicated that the instruction materials were of good quality for the classificatory level.

The downward shift of the P-curve represents the sensitivity and the uniformity of learning gain, which were observed in comparing the results (three S-P charts) of the paper-pencil tests. The progress of learning was further observed from three more pieces of evidence: (a) P_j for every item increased from the pre-test to the post-test 1 to the post-test 2 as in P_j for item 1 at classificatory level, which increased from 30% to 82% to 95%, showing the sensitivity to learning gain. (b) All the CP_j values of the post-test 2 for the three levels were less than 0.41, meaning that all items were good. (c) In the plot of P_j vs. CP_j, all items were in the upper left quadrant, meaning that they were of good quality.

3. Correlation between the results of the tests and the task performances

At the classificatory level those students (95.6%) who obtained good experimental results of high yield and high purity also did well in the post-test 2.

The progress of learning discussed above was further confirmed by the correlation among the results of the rational set of assignments, i.e., the third correlation mentioned in the second paragraph under III. Results and Discussion. Validation with respect to learning transfer after training was made by observing the individual performance profile (Table 2), which shows pass (+) or fail (−) in the rational set of laboratory assignments. In Table 2, the first assignment of concrete level (naphthalene) was typical case that trained student's accurate performance. Students who failed in the first task (A) were required to

Table 2. Attainment levels of individuals in sublimation.

St. No.	*Concrete level* P.P.	Practical[a] 1st	2nd	*Identity level* P.P.	Practical[b] 1st	2nd	*Classificatory level* P.P.	Practical[c] 1st	2nd	3rd	Level attained
1	+	+		+	+		+	+			Classificatory
2	+	+		+	+		–	–	–	–	Identity
3	+	+		+	+		+	+			Classificatory
4	+	+		+	+		+	+			Classificatory
5	+	+		+	+		+	+			Classificatory
6	+	+		+	+		+	–	+		Classificatory
7	+	+		+	+		+	+			Classificatory
8	+	+		+	+		+	–	–	+	Classificatory
9	+	+		+	+		+	+			Classificatory
10	+	+		+	+		+	+			Classificatory
11	+	+		+	+		+	+			Classificatory
12	+	–	+	+	+		+	+			Classificatory
13	+	+		+	+		+	–	–	+	Classificatory
14	+	–	+	+	+		+	+			Classificatory
15	+	+		+	+		+	–	+		Classificatory
16	+	+		+	+		+	+			Classificatory
17	+	+		+	+		+	+			Classificatory
18	+	+		+	+		+	+			Classificatory
19	+	+		+	+		+	+			Classificatory
20	+	+		+	+		+	+			Classificatory
21	+	+		+	+		+	+			Classificatory
22	+	+		+	+		+	+			Classificatory
23	+	+		+	+		+	+			Classificatory

P.P. Paper-pencil test (Post-test 2).

[a] Sublimation of naphthalene. [b] Sublimation of camphor.

[c] Sublimation of and unknown solid after successfully completed five or more of the six assignments.[d]

[d] Six assignments:

Compound	*p*-dichloro-benzene	hexachoro-ethane	1-naphthol	anthra-quinone	caffeine	*p*-benzo-quinone
Sublimation pressure	atmospheric	atmospheric	reduced	reduced	reduced	reduced
Coolant	ice	air	water	water	water	water

repeat the same task after remedial instruction. The first assignment of identity level (camphor) is comparable case, which trained student's "identification-reproduction" ability. Students who failed in the second task (B) were given a third task (C) selected from the rest of the rational set. Assignments other than A and B (*p* -dichlorobenzene, hexachloroethane, anthraquinone, caffeine, *p* -benzoquinone, and 1-naphthol; see Table 2, Footnote d.) have representative attributes and should be able to train a student's "generalization to all ordinary cases" ability. Students were considered to reach the classificatory level only if they successfully completed 80% or more of the assigned cases. The ability was confirmed by successfully performing an unknown task taken randomly from a large collection of cases of sublimation. The last column records that twenty-two (95.6%) students reached the classificatory level while only one student remained at the identity level. These facts were confirmed by the learning gain shown in individual performance profiles (Table 1). The progress of learning observed as discussed above indicates the effectiveness of our implementation method for mastery learning of sublimation technique.

IV. Conclusion

In this study, instruction materials were prepared and instruction strategies were developed for instructing the mastery learning of the sublimation technique. They were organized to bring the students through three successively higher learning levels: concrete, identity, and classificatory. The efficiency of instruction was evaluated by the degree of learning progress. The later was evaluated by positive cor-relations between two consecutive tests, between task performance and test results, and the results of a set of laboratory assignments. The progress of learning was observed in the rightward shifts of the S-curves and the downward shifts of the P-curves during a set of assignments. CP_j values of all items are less than 0.44. In the plots of P_j vs. CP_j, all items are in upper left quadrant. These facts indicate that all items were of good quality. An acceptably small degree of anomalous item patterns in Chart 3 reflected clarity in instruction. In each post-test 2 for the three levels all the CS_i values for individual students were less than 0.50 and all the three D^* values were less than 0.4022. Small CS_i and D^* values indicated an acceptably small degree of learning difficulties and erratic studies (careless mistakes, copying or guessing responses) after instruction. Those students (100% for both the concrete and the identity levels and 95.6% for the classificatory level) with high scores in the paper-pencil test indeed obtained high yield and high purity. These facts were consistent with the learning gain shown in individual performance profiles. Once the students mastered the technique, they kept the ability. The progress of learning observed as discussed above indicated the effectiveness of our implementation method for mastery learning of sublimation technique. The high reliability and validity of the instruments were further tested by patterns of S-P chart, CP_j (less than 0.50), P_j (higher than 0.50), and D^* (less than 0.50) values. These instructional materials and strategies are satisfactory for a college introductory organic chemistry laboratory course. The methodology used in this study can be extended advantageously to the study of instruction on other chemistry experimental techniques for a class of about 40 students.

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References

Cheronis, N. D., & Entrikin, J. B. (1963). *Identification of orgainc compounds*. NY: Interscience Publishers, Inc.

Dumas-Carré, A., & Larcher, C. (1987). The stepping of learning and evaluation. *International Journal of Science Education, 9* (1), 93-104.

Fieser, L. F., & Williamson, K. L. (1987). *Organic experiments* (6th ed.). Lexington: D. C. Health and Company.

Gagnè, R. M. (1987). *Instructional technology: Foundations*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Herron, J. D., Cantu, L. L., Ward, R., & Srinivasan, V. (1977). Problem associated with concept analysis. *Science Education, 61* (2), 185-199.

Johnstone, A. H. & Wham, A. J. B. (1982). The demand of practical work. *Education in Chemistry, 19* (3), 71-73.

Klausmeier, H. J., & Sipple, T. S. (1980). *Learning and teaching concepts. A strategy for testing application of theory*. New York: Academic Press, Inc.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.

Roberts, R. M., Gilbert, J. C., Rodewald, L. B., & Wingrove, A. S. (1985). *Modern experimental organic chemistry*. NY: Saunders College Publishing.

Sato, T. (1980). The S-P Chart and the Caution Index. *NEC educational information bulletin 80-1*. C & C System Research Laboratories, Nippon Electric Co., Ltd.

Tamir, P. (1989). Training teachers to teach effectively in the laboratory. *Science Education, 73* (1), 59-69.

Wang, C. H. (1990). *Computer program for S-P chart analysis*. Unpublished.

Wang, C. H. & Horng, J. M. (1991). Construction and validation of instrument to assess chemistry manipulative technique-sublimation. *Bulletin of National Taiwan Normal University, 36*, 219-238.

Williamson, K. L. (1987). *Microscale organic laboratory*. Lexington: D. C. Health and Company.

化學實驗技能精熟學習之設計

昇華技能

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摘　要

本研究開發昇華實驗技能精熟學習教材及教學策略，以使學生達到三個連續的學習達成階層：具體、辨認及歸納階層。此教導效果用學生學習進步的情形加以評定，即用前、後測之間、實作成果與測驗成績之間、以及一組實驗活動之間等的正相關來評量。學生學習的進步情形，從一組實驗活動中S曲線向右移動，P曲線向下移動可看出來。紙筆測驗每一試題的CP_j值都小於0.44。以各題的P_j對CP_j作圖，所有試題均位於左上方象限中，此等結果顯示所有試題都良好。三個學習達成階層後測2中每位學生的CS_i值都小於0.50和D^*值都低於0.4022之事實，表示學生的學習沒有不正常的現象（如先修技能不足、錯誤學習、不小心犯錯、抄襲或猜測答案等）。紙筆測驗分數高的學生，其昇華實作所得的晶體產率高、純度也高，其一致程度在具體與辨認階層皆爲95.6％。這些事實可由每位學生學習的進步情形得到驗證，即沒有學生由已經學會昇華技能變成不會的事實。由以上結果可以顯示本研究所開發的昇華技能精通學習教材及教學策略，對於昇華技能的精熟學習相當有效，適合大二有機化學實驗課程使用。本研究所用的方法，可推廣應用於其他化學實驗技能的教學研究上。

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Predictors of Elementary School Students' Science Achievement

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ABSTRACT

The purpose of this study was to identify strong predictors of science achievement for grades three to five in the Republic of China. There were 38 schools (2950 students) involved. Selected variables included: (1) students' background variables including students' parental education and occupation, students' age and gender; (2) academic variables including Chinese, mathematics, and science achievement; (3) school size; and (4) teacher inservice training.

Data were analyzed through frequency, correlation and multiple regression. Stepwise multiple regression was run separately for each semester by using student's background, Chinese and mathematics final scores, and previous science test scores as predictors; the current science score was the criterion.

Results indicated that the selected variables explained an average of 50% of the variance of science achievement. Home background accounted for 9-13% of the variance. Within the home background category, fathers' educational level was the strongest predictor and accounted for about 4% of the explained variance. Previous science scores accounted for 10-45% of the variance with a mean of 32%. When home background and scholastic ability were removed, previous science scores accounted for 10-15% of the variance. Mathematics achievement accounted for an average of 32% of the explained variance (20-30% of the variance when home background was removed).

Inservice teacher training, school size, and students' gender each individually accounted for less than 1% of the variance of science achievement.

Further studies related to the effectiveness of inservice teacher training, congruence of curriculum objectives and science tests items, and characteristics of effective schools are recommended.

Key words: science achievement, inservice teacher education, family background, gender, elementary school science.

I. Introduction

The Republic of China has modified the country's elementary school curriculum grade by grade since 1978. With the Fall semester of 1984, the current science curriculum has been used in all grades.

In order to determine the impact of the current science curriculum, a follow-up project has been conducted in the Taiwan Provincial Ban-Chyon Teacher Center since 1979. Ninety-one schools were involved in the study. Each school randomly assigned one class to be an experimental class. From first to sixth grade, the same class was kept as an experimental class. Teachers who taught science to an experimental class received two weeks of intensive training. Both experimental and non-experimental students received the same test at the end of each semester that was developed by the project committee.

Reform of the science curriculum was started in

1988. However, curriculum reform is a longitudinal and continuous process. Both the design and development of a new science curriculum and the implementation of the current curriculum need a research base. It is expected that if more information related to the current science curriculum can be provided, it will help improve the current science curriculum and develop the new science curriculum. Several research studies related to the current science curriculum had been completed. However, none of these studies was concerned with variables related to student science achievement. There was a need to identify variables related to science achievement for these students and to determine which significant variables can be emphasized (if positive) or reduced (if negative).

The purpose of this study was to provide basic data to identify the variables that are the strongest predictors of elementary school student science achievement.

II. Review of Related Literature

Centra and Potter (1980) proposed a model in which six clusters of variables interact to affect science achievement (Fig.1). Based on this model, variables in this study were reviewed and selected.

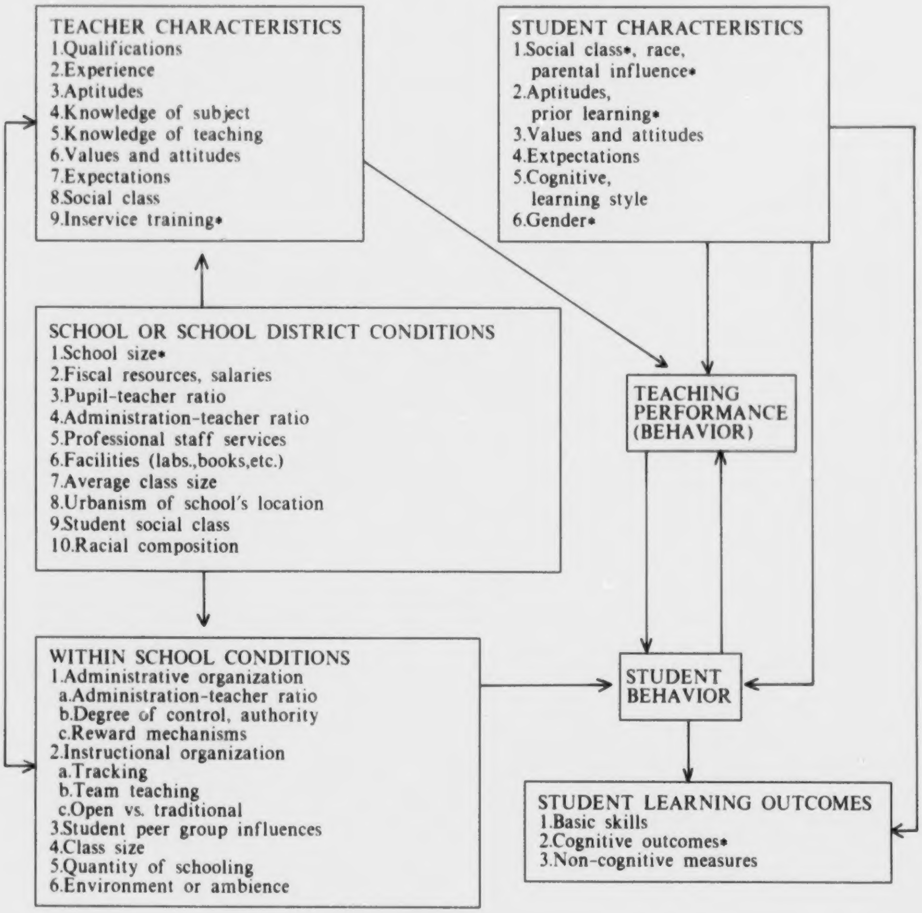
TEACHER CHARACTERISTICS
1.Qualifications
2.Experience
3.Aptitudes
4.Knowledge of subject
5.Knowledge of teaching
6.Values and attitudes
7.Expectations
8.Social class
9.Inservice training•
STUDENT CHARACTERISTICS
1.Social class•, race, parental influence•
2.Aptitudes, prior learning•
3.Values and attitudes
4.Extpectations
5.Cognitive, learning style
6.Gender•
SCHOOL OR SCHOOL DISTRICT CONDITIONS
1.School size•
2.Fiscal resources, salaries
3.Pupil-teacher ratio
4.Administration-teacher ratio
5.Professional staff services
6.Facilities (labs.,books,etc.)
7.Average class size
8.Urbanism of school's location
9.Student social class
10.Racial composition
TEACHING PERFORMANCE (BEHAVIOR)
WITHIN SCHOOL CONDITIONS
1.Administrative organization
a.Administration-teacher ratio
b.Degree of control, authority
c.Reward mechanisms
2.Instructional organization
a.Tracking
b.Team teaching
c.Open vs. traditional
3.Student peer group influences
4.Class size
5.Quantity of schooling
6.Environment or ambience
STUDENT BEHAVIOR
STUDENT LEARNING OUTCOMES
1.Basic skills
2.Cognitive outcomes•
3.Non-cognitive measures

Fig. 1. Centra and Potter's model of teaching and learning.
• Variables selected for this study

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Student characteristics

Studies have shown that the correlation between home background and science achievement ranged from .25 to .42 (Kremer & Walberg, 1980); this has accounted for 10-18% of the variance of science achievement (Fleming & Malone, 1982; Kahl, 1982; Walberg, 1986; Walker, 1976). Parents' educational level had the strongest influence on students' learning (Abeti, 1983; Lu, 1976; NAEP, 1973; Sanguinetty, 1983).

Scholastic ability (mathematics, language, and general ability) showed slighly higher correlation (around .40 to .50) with science achievement than did home background. About 16-25% of the variance in science achievement was explained by scholastic ability (Brown, 1983; Crocker & Butts, 1986; Galitsis, 1986; Horton, 1986; Thorndike, 1973).

Prior knowledge had moderate correlation with science achievement and accounted for 16-25% of the variance in science achievement (Boulanger, 1980; Kahl, 1982; Keeves, 1985).

Gender differences correlated to science achievement with a mean correlation of .04 and accounted for less than 2% of the variance. Boys showed slightly higher achievement than did girls (Hueftle *et al.*, 1983; Kahl, 1982; Maehr & Steinkamp, 1983).

Teacher characteristics

Literature reviews showed that teachers' qualifications, expectations, knowledge and experience were variables that could influence student learning. However, the mean correlations tended to be low compared to student characteristics. Data on teacher characteristics usually accounted for less than 5% of the variance in science achievement (Biddle, 1985; Druva & Anderson, 1982; Purkey & Smith, 1983).

Some studies showed that inservice teacher education had a significant impact on teachers (Bedwell, 1974; Halprin, 1985; Lawrenz, 1986). However, few researchers attempted to determine whether inservice education impacted student learning. Some studies reported significant impact on students (Champagne, 1980; Druva & Anderson, 1982; Hunkler, 1971).

School or school district conditions

Research indicated that there was a slight relationship between school difference and student achievement. The school effect was underestimated and confounded by students' background variables (Centra & Potter, 1980; NAEP, 1977).

Based on Comber and Keeves' study (1973), school size correlated significantly with students' science achievement. Depending on the number of classes and location of schools, there are three categories of school size in elementary schools in the Republic of China. Larger schools usually have better facilities. School size was selected as a predictor in this study.

Within school conditions

Research reviews have indicated some within school conditions related to student achievement (Walberg, 1986). However, the number of school days, instruction time and the organization of instruction are essentially the same in elementary schools in the Republic of China. No variable was selected within this cluster of variables.

Teacher performance (behavior)

Teacher performance and behavior had an impact on students' achievement (Howe *et al.*, 1986; Lott, 1982; Wise & Okey, 1982). However, compared to other student variables, such as home background and ability, teacher performance and behavior usually have contributed less variance (Welch *et al.*, 1986).

Student behavior

Research has indicated that the relationship between a student's behavior and his achievement is not simple. How much variance of student science achievement can be explained by student behavior is not clear. This is a complex area of study (Cairns, 1985; Smyth, 1985).

Variables selected in this study were: 1) student background variables, including gender, age, and parents' education and occupation; 2) academic variables, including Chinese, mathematics, and science achievement for each semester; 3) school variables, including teacher inservice education (group) and school size.

III. Method

Population and sample

The 91 elementary schools that had been involved in the Elementary School Science Curriculum Study (1979-1986) were the population for this study. Thirty-eight schools (2950 students) were selected from the population. Three steps were taken to select and retain schools that could be analyzed: 1) the study included only those that had at least five semesters of science test results, including the first semester of third grade and the second semester of fifth grade; 2) insufficient data on parental occupation or education eliminated schools from the study; and 3) small schools (schools with enrollment of less than 12 classes) were deleted from this study because non-experimental classes were not available.

The non-experimental class for each school was randomly selected from classes that were in the same grade as the experimental class of each experimental school.

Treatment

The study compared science achievement of two different classes. Teachers who taught the experimental classes attended a two-week training program conducted by the Ban-Chyon Teacher Center at the beginning of each semester. Teachers who taught the nonexperimental classes received no special training. The two-week training program included lectures on learning theories, teaching methods, evaluation, and hands-on activities for all science units of the coming semester. Teachers also went to local elementary schools to observe model teachers' teaching or to practice teaching themselves.

It was planned that the same teacher taught science to the same class from the first grade to the sixth grade. The cummulative effect of teacher training was the second treatment of this study.

Instrument

The Science Test for each semester was designed by the committee. The test was tried and modified at least three times by the committee members, who included scientists, science educators and selected elementary school teachers. Based on committee members' review, tests had content validity. Test reliabilities (KR-20) ranged from .68 to .80 (Table 1). The reliabilities are acceptable. The lower reliability of the first semester may have been due to fewer test items.

Table 1. Reliability (KR-20) of the science tests

Test	No. of Items	KR-20	No. of Students
Grade 3, Semester 1	18	.68	2795
Grade 3, Semester 2	20	.73	2543
Grade 4, Semester 1	20	.78	2122
Grade 4, Semester 2	20	.75	2851
Grade 5, Semester 1	20	.77	2884
Grade 5, Semester 2	20	.80	2929

At the end of each semester, all the students in each school completed the same science test at the same time. The tests for the experimental classes were administered by committee members and the other classes were given the test by the classroom teachers. Both the committee members and the classroom teachers used the same Test Guide. The criteria for correct answers were specified in the Test Guide; all the tests were graded using the same criteria.

Data collection

The 38 schools provided data of students' parental education and occupation, students' sex and age, and final scores for Chinese and mathematics from grade three to grade five.

The Ban-Chyon Teacher Center provided data of school size and science test results.

Data analysis

All the data were coded dichotomously except for Chinese, mathematics grades, and science test scores.

The data were analyzed for frequencies, correlations, and stepwise multiple regressions by a SPSSX package.

IV. Results

The results (Table 2) indicated that correlation coefficients between student science achievement and teacher inservice training were low, even there were three semesters statistically significant. There was also no increasing tendency of correlation coefficents among semesters. Neither inservice teacher education nor the cumulative effect of inservice teacher education had significant impact on students science achievement.

Table 2. Correlations between science achievement and teacher inservice training

Variable	S1	S2	S3	S4	S5	S6
Group	.06[a]	-.01	.02	.05[b]	.00	.05[a]

a $p<.01$
b $p<.05$
S1: Science achievement of 1st semester of 3rd grade.
S2: Science achievement of 2nd semester of 3rd grade.
S3: Science achievement of 1st semester of 4th grade.
S4: Science achievement of 2nd semester of 4th grade.
S5: Science achievement of 1st semester of 5th grade.
S6: Science achievement of 2nd semester of 5th grade.
Group: Experimental classes (teachers received training) were coded as one; non-experimental classes (teachers received no inservice training) were coded as zero.

Home background accounted for 9-13% of the variance. Within the home background category, fathers' educational level was the stongest predictor and accounted for about 4% percent of the explained variance (Table 3).

Table 3. Regression results of student background variables and school size to student science achievement

Semester	R Square	First Predictor(RSQ)
Grade 3, Semester 1	.09	FED3 (.04)
Grade 3, Semester 2	.10	FED3 (.04)
Grade 4, Semester 1	.13	FED3 (.06)
Grade 4, Semester 2	.11	FED6 (.04)
Grade 5, Semester 1	.09	FED3 (.04)
Grade 5, Semester 2	.11	FED3 (.05)

FED3: Father's highest education is elementary school.
FED6: Father's highest education is college or higher.

Student home background, and Chinese and mathematics scores accounted for 28-42% of the variance of science achievement. Mathematics was the strongest predictor and accounted for an average of 32% of explained variance (Table 4).

Table. 4. Regression results of student background variables, school size, Chinese and mathematics semester grades to student science acievement

Semester	R Square	Rirst Predictor (RSQ)
Grade 3, Semester 1	.31	M1 (.28)
Grade 3, Semester 2	.28	M2 (.24)
Grade 4, Semester 1	.40	M3 (.36)
Grade 5, Semester 2	.38	M4 (.35)
Grade 5, Semester 1	.37	M5 (.34)
Grade 5, Semester 2	.42	M6 (.39)

M1:Math. score of the first semester of the third grade.
M2:Math. score of the second semester of the third grade.
M3:Math. score of the first semester of the fourth grade.
M4:Math. score of the second semester of the fourth grade.
M5:Math. score of the first semester of the fifth grade.
M6:Math. score of the second semester of the fifth grade.

All variables selected in this study explained an average of 50% of the variance of science achievement. Previous science test scores and mathematics final scores were the first two strong predictors. Previous science scores accounted for 10-45% of the variance, with an average of 32% (Table 5).

Table 5. Regression results of student background variables, school size, Chinese and mathematics semester grades and previous science test scores to current science acievement

Semester	R Square	1st Predictor (RSQ)	2nd Predictor (RSQ)
Grade 3, Semester 2	.38	S1 (.30)	M2 (.06)
Grade 4, Semester 1	.52	M3 (.36)	S1 (.10)
Grade 4, Semester 2	.55	S3 (.45)	M4 (.06)
Grade 5, Semester 1	.48	S3 (.34)	M5 (.10)
Grade 5, Semester 2	.58	S5 (.43)	M6 (.09)

M2: Math. score of the second semester of the third grade.
M3: Math. score of the first semester of the fourth grade.
M4: Math. score of the second semester of the fourth grade.
M5: Math. score of the first semester of the fifth grade.
M6: Math. score of the second semester of the fifth grade.
S1: Science test score of the first semester of the third grade.
S3: Science test score of the first semester of the fourth grade.
S5: Science test score of the first semester of the fifth grade.

When home background, Chinese and mathematics grades were removed, previous science scores accounted for 10-15% of the variance.

Girls showed significantly better achievement than did boys in Chinese. However, the correlation was not high (r=.16 to r=.19). There was no difference in mathematics scores between boys and girls. In science achievement, the difference between boys and girls was not statistically significant and the correlation coefficients were low (r=.035 to r=.100). Gender accounted for less than 1% of the variance of science achievement.

School size and student age did not have significant impact on student science achievement and accounted for less than 1% of the variance.

Subjects were correlated highly and significantly. Correlation coefficents between Chinese and mathematics ranged from .67 to .79 over six semesters; from .45 to .60 between science and mathematics; and from .40 to .50 for science and Chinese.

V. Conclusions and Discussion

Parental education was significantly related to student academic achievement. This finding is consistent with other findings (Ahmann, 1982; NAEP, 1973). Parents who received higher education would realize the importance of education, pay more attention to their childrens' learning, and try their best to provide a better learning environment for their children. These findings support the importance of education, not only for current students, but also for its impact on the learning of the next generation.

Students who achieved successfully in science also performed well in mathematics and Chinese. The results are close to the findings from meta-analysis of Fleming and Malone (1982). High correlations among Chinese, mathematics, and science indicate that learning is holistic, especially in elementary school level.

Previous science achievement is a strong predicator of science achievement. Students who learn the science material required in previous semesters, regardless of whether their teachers received inservice training or not, make better progress in later years. This finding is especially meaningful when we view learning from the standpoint of constructivism. Children develop their science knowledge. If they lack the early concepts, it is very hard for them to buildup later learning correctly. Meanwhile, misconceptions are generated.

Boys scored slightly higher, but not significantly higher, than girls in science achievement for all six semesters. This finding is consistent with others (Maehr & Steinkamp, 1983).

Neither the inservice teacher training program nor the cumulative effect of the training program significantly correlate with studen science achievement. There are several possible explanations for this finding. The first possibility is that the inservice teacher training program was not effective from the perspective of influencing student achievement; therefore, it did not correlate significantly with student science achievement. The second possibility is that the experimental group teachers helped the non-experimental group teachers. This kind of "contamination" would have decreased the differential effect of the inservice teacher training program on science achievement. A third alternative explanation is that some teachers made effective use of the inservice education and some did not, thus decreasing the impact of the inservice work. The fourth possibility is that non-experimental group teachers might not have followed the Test Guide exactly when they gave tests to the non-experimental group students. It is unknown whether classroom teachers followed the instructions on the Test Guide or tried to explain for students more; this could have helped non-experimental class students achieve higher levels. The reason why the inservice teacher education (group) did not explain better the variance of science achievement obviously requires further study.

The model selected from the literature provided an average of 60-70% of the variance. In this study, a mean of 50% of the variance was explained, varying from 38 to 58% of the variance. The addition of variance related to within school conditions and teacher performance would probably add the most to the explained variance. While some variables related to student behavior and student characteristics might add more to the explained variance, these were probably explained by the achievement variables included. Teacher characteristics such as knowledge and expectations might also add to the explained variance.

VI. Recommendations

Based on the analyses in this study, the following studies and programs are recommended.

1. Further analysis should be done to determine the impact of the inservice teacher education program on student science achievement. It is recommended that another 38 elementary schools be selected and that a class from each school at each grade level (three, four, and five) be studied.
2. The congruence among science curriculum goals, instruction, instructional materials and evaluation should be analyzed to help improve science teaching. The following studies are recommended: a) check the congruence between science tests and curriculum; b) check the congruence between science tests and instruction; c) analyze the difficult items.
3. Help low achievers (including science, Chinese, and mathematics) as early as possible. Evidence indicated that early success was related to later success. Programs should be established to help students master essential concepts and to provide assistance for children who do not maintain grade achievement levels.
4. The high correlations among subjects may indicate that the learning of one subject often influences the learning of other subjects. To improve curriculum, horizontal connections among subjects should be taken into consideration as well.
5. Design a continuing educational program for fathers who have lower educational levels and who would like to have a chance to study again; this would encourage them to pay more attention to their childrens' learning.
6. This study analyzed mean achievement scores of students. Data should also be examined to identify gain scores for students and to examine the impact

of teacher performance and student behavior on classes with the best gain scores.

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References

Abeti, S. L. (1983). The relationship between social environment in the home and achievement in science--Uganda. *African Studies in Curriculum Development and Evaluation.* ED 250 154.

Ahmann, J. S. (1982). Educational achievement trends: A mix of gains and losses. *Iowa Educational Research and Evaluation Bulletin, October,* 16-23. ED 223 476.

Bedwell, L. E. (1974). The effects of training teachers in question-asking skills on the achievement and attitudes of elementary pupils. *Dissertation Abstracts International, 35/09-A* 5980.

Biddle, B. J. (1985). Teacher role. In: Husen, T. and Postlethwaite, T. N., *The International Enclyclopedia Education,* Vol. 9, 5022-5032. New York: Pergamon Press.

Boulanger, F. D. (1980). Instruction and science learning: A quantitative synthesis. In: Walberg, H. J. *et al., A meta-analysis of productive factors in science learning grade 6 through 12,* pp. C1-C23. University of Illinois at Chicago Circle, Chicago, Illinois.

Brown, N. E. (1983). The use of selected characteristics of ability and achievement in a multi-track science curriculum. *Dissertation Abstracts International, 43/A,* 3795.

Cairns, L. G. (1985). Behavior problems in the classroom. In: Husen, T. and Postlethwaite, T. N., *The international encyclopedia of education,* pp. 451-456, Vol. 1. New York: Pergamon Press.

Centra, J. A. & Potter, D. A.(1980). School and teacher effects: An interrelational model. *Review of Educational Research, 50* (2), 273-291.

Champagne, D. W. (1980). Does staff development do any good? *Educational Leadership,* Feb.

Comber, L. C. & Keeves, J. P. (1973). *Science education in nineteen countries. International Studies in Evaluation I.* New York: John Wiley & Sons.

Crocker, B. & Butts, D. P. (1986). The relationships between performance on science thinking skills and reading comprehension skills of elementary students. In: Blosser, P. E. and Helgeson, S. L., *Abstracts of Presented Papers on NARST-59th Annual Conference,* March, 1986, S. F. CA.

Druva, C. A., & Anderson, R. D. (1983). Science teacher characteristics by teacher behavior and by student outcome: A meta-analysis of research. In: Anderson, R. D. *et al., Science Meta-Analysis Project: Final Report of NSF Project,* No. SED 80-12310. University of Colorado, Boulder, Colorado.

Fleming, M. L. & Malone, M. R. (1982). The relationship of student characteristics and student performance in science. In: Anderson, R. D. *et al., Science Meta-Analysis Project: Final Report of NSF Project,* No. SED 80-12310, pp. 561-638. University of Colorado, Boulder, Colorado.

Galitsis, A. (1986). An analysis of factors used to predict success in the New York regents biology course, In: Blosser, P. E. and Helgeson, S. L., *Abstracts of Presented Papers on National Association for Reserarch in Science Teaching-59th Annual NARST Conference,* S. F. CA.

Halperin, D. (1985). *A staff development program to increase teacher competency in mathematics education for the early years.* ED 262 917.

Horton, P. (1986). The effect of writing assignments on achievement in college general chemistry. In: Blosser, P. E. and Helgeson, S. L., *Abstracts of Presented Papers on Nationasl Association for Research in Science Teaching-59th Annual NARST Conference, S. F. CA.*

Howe, R. W., Blosser, P. E., Suydam, M. N., Helgeson, S. L., and Disinger, J. F. (1986). *Persistent problems in precollege mathematics, science, and environmental education: Issues, trends, and recommendations.* ERIC Clearinghouse for science, mathematics, and environmental eduaction. The Ohio State University.

Hueftle, S. T., Rakow, S. J., & Welch, W. W. (1983). *Image of science: A summary of results from the 1981-82 national assessment in science.* University of Minnesota.

Hunkler, R. (1971). An evaluation of a short-term inservice mathematics program for elementary school teachers. *School Science and Mathematics,* Oct.

Kahl, S. R., & others (1982). *Sex-related differences in precollege science: Findings of the Science Meta-Analysis Project.* ED 216 909.

Keeves, J. P. (1985). Path analysis. In: Husen, T, & Postlethwaite, T. N., *The International Encyclopedia of Education,* 3806-3813. New York: Pergamon Press.

Kremer, B. K. & Walberg, H. J. (1980). A synthesis of social and psychological influences on science learning. In: Walberg, H. J. *et. al., A meta-analysis of productive factors in science learning grade 6 through 12,* pp. E1-E31. University of Illinois at Chicago Circle, Chicago, Ill.

Lawrenz, F. (1986). Teacher to student transfer in energy education. *School Science and Mathematics, 86* (1), 1-9.

Lott, G. W. (1982). The effect of inquiry teaching and advance organizers upon student outcomes in science. In: Anderson, R. D. *et al., Science Meta-Analysis Project: Final Report of NSF Project,* No. SED 80-12310, 322-372. University of Colorado, Boulder, Colorado.

Lu, F. M. (1976). The analysis of family background of low achievers in elementary schools in the Republic of China. *Journal of Research Reports of the Taiwan Provincial Cha-I Junior Teacher College, 7,* 206-233.

Maehr, M. L. & Steinkamp, M. (1983). *A synthesis of finding on sex differences in science education research (Final Report).* ED 229 226.

National Assessment Findings in Science 1969-1970--What do they mean? (1973). ED 091 169.

National Assessment of Educational Progess (1977). *Science Technical Report: Summary Volume.* Educational Commission

of the States, Denver, Colorado. ED 141 135.

Purkey, S. C. & Smith, M. S. (1983). Effective schools: A review. *The Elementary School Journal, 83* (4), 427-452.

Sanguinetty, J. A. (1983). *Academic achievement, school quality and family background: study in seven Latin American countries.* ED 233 448.

Smyth, W. J. (1981). Research in classroom management: studies of pupil engaged learning time as a special but instructive case. *Journal of Education for Teaching, 7* (2), 127-145.

Thorndike, R. L. (1973). *Reading comprehension education in fifteen countries. International Studies in Evaluation III.* New York: Macmillan Publishing Company.

Walker, D. A. (1976). *The IEA six subjects survey: An emperical study of education in twenty-one countries. International Studies in Evaluation IX.* New York: John Wiley & Sons.

Welch, W. W., Walberg, H. J., & Fraser, B. J. (1986). Predicting elementary science learning using national assessment data. *Journal of Research in Science Teaching, 23* (8), 699-706.

Wise, K. C. & Okey, J. R. (1982). The effects of various science teaching strategies on achievement. In: Anderson, R. D. *et al., Science Meta-Analysis Project: Final Report of NSF Project,* No. SED 80-12310, 287-311. University of Colorado, Boulder, Colorado.

預測國小學童科學成就之變因

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摘 要

本研究的目的在於瞭解預測我國國小三至五年級學童科學成就之變因。38所國小（2950人）參與研究。所選擇的變因有(1)家庭背景；包括學童父母的教育及職業，學生的年齡及性別；(2)學業成績：包括國語、數學、及科學成就；(3)學校大小；(4)任課教師是否接受過在職訓練。資料以SPSSX套裝軟體分析各項變因之頻率分布，相關及迴歸分析。

研究的結果顯示本研究所選擇之變因平均可解釋50%的科學成就之變異。其中父親的教育可說明4%之變異；家庭背景變因可說明9-13%之變異；過去的科學成就可說明10-45%之變異；數學成績可解釋20-30%之變異。

教師之在職訓練、學校大小、學生的性別各能解釋1%以下之變異。

探討教師在職訓練之成效，科學課程與測驗之間之一致性及有效學校之特色均爲進一步可行之研究。

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The Design of an Evaluation System for a CAI Courseware

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ABSTRACT

While using the CAI courseware, the teacher usually neglects two important pieces of information. The first one is about the courseware itself, which may be the elapsed time of using courseware, the number of times used or flow path of the courseware, etc. This information can be used to evaluate the performance of this courseware. The second one is about the student himself, which is recorded while the student takes interaction with the courseware. This paper provides a method to help the teacher a evaluate the courseware and the learner's performance. This method will provide a management environment in which these two important pieces of information are collected and analyzed to evaluate the courseware and the learner's performance.

Key words: CAI, graph theory, finite state machine, courseware, evaluation strategy, learning path.

I. Introduction

The scheme of evaluatuon about CAI is generally discussed (Sato, 1973, 1974). One of the widely known methods in learning diagnosis is the "Student Problem Chart Analysis" (Sato, 1984, 1986). We can use the list of student's scores and the corresponding questions to judge the suitability of the questions and learning behavior of students. Thus, this skill can evaluate the qualitative performance of the courseware. However, this scheme will face three problems (Chen, 1986). First, in the qualitative evaluation, various experiences produce different evaluated statements on the same thing. Second, it cannot clearly indicate the real characteristics of the phenomenon; further research must be adopted in order to make an accurate conclusion. Third, the justification of qualitative evaluation will be different in different cases; moreover, it can not exactly describe the quantities of the differences.

The argument is unavoidable: Basically, the scheme of qualitative evaluation would take a heuristic method as the main orientation. In order to evaluate the courseware quantitively, we need a computer to collect the user's learning records to judge the arranged order of the courseware and suitability of the teaching material. That is, the learning records include implicitly the information of learning behavior and their quantities. In short, how to establish a scheme of quantitative evaluation is the main goal of this paper, as well as using these quantities to estimate the courseware itself and user's learning behavior.

In this paper, we use the graph theorem to represent the relationship among teaching elements within a given courseware. An algorithm is provided to illustrate the detailed steps of this representation. Then, according to this representation and the finite state machine concept, the courseware can be considered as a directed graph associated with some attracted attributes. So, under a weight function we can use the Dijkstra technique, which is a shortest path algorithm for a graph that is usually utilized in the computer science field, to obtain the desired results about CAI. The Dijkstra algorithm is described in algorithm B. Since the weight function in the Dijkstra algorithm depends on the particular application, we approach it by means of quantitive analysis to show the quantity measurement rule. Finally, we discuss some strategies of a quantitative measurement rule to display our research effectiveness, i.e., this mathematical analysis and these equations can be easily integrated into a CAI system to provide an evaluation for the user and the courseware.

II. Hierarchical Structure of the Courseware

First, the teaching content can be divided into elements according to theme, conception, and skill as is shown in figure 1. Then directed relationships can be establised between them, as shown in figure 2, owing to some factors such as logic, experience, subject and intuition. Each directed relationship in figure 2 is combined integrally together. Figure 3 shows the resulting graph. The resulting graph can be represented by a connection matrix A, shown as follows:

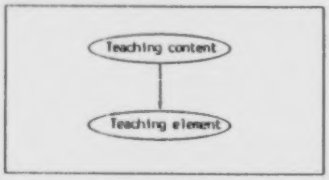

Fig. 1. Divide teaching content into teaching elements according to theme, conception, and skill.

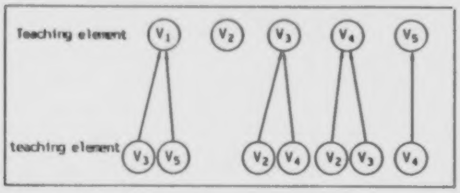

Fig. 2. Directed relationships among the teaching elements.

$$A = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

In this connection matrix A, $V_{ij} = 1$ denotes the existence of directed relationship $V_i \rightarrow V_j$.

If K is a positive number and I is a unit matrix, there exists one K to satisfy the following condition on the Boolean addition and multiplication: $(A+I)^{k-1} \neq (A+I)^k = (A+I)^{k+1} = M$. Then, M could be called the reachability matrix (Chimura, 1984). $M_{ij} = 1$ means that V_i directly or indirectly generates a relationship with V_j through some teaching elements (zero or above). Therefore, the reachability M matrix can be represented as

$$M = (A+I)^3 = (A+I)^4 = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 \end{pmatrix}$$

In addition, $R(V_i)$ denotes the reachability set of teaching elements that V_i may directly or indirectly reach, and $A(V_i)$, the antecedent set, denotes the set of teaching elements that can reach the teaching element V_i. $R(V_i) \cap A(V_i)$ shows the set that V_i may directly or indirectly reach. The following list is the content of three sets:

V_i	$R(V_i)$	$A(V_i)$	$R(V_i) \cap A(V_i)$
1	1	1,2,3,4,5	1
2	1,2,3,4,5	2	2
3	1,3,4,5	2,3,4	3,4
4	1,3,4,5	2,3,4	3,4
5	1,5	2,3,4,5	5

If $R(V_i) \cap A(V_i) = R(V_i)$, then it shows that V_i is the top level of teaching elements of hierarchical structure. In figure 3, V_1 satifies this condition. The second level of teaching elements of hierarchical structure is generated by moving V_1 from figure 3 and finding a teaching element V_i to satify $R(V_i) \cap A(V_i) = R(V_i)$. Repeat the same steps until another level of other teaching elements have been decided. Finally, the directed graph among these teaching elements results in a hierarchical structure shown in figure 4. Therefore the structure of teaching material of each courseware may be presented by a hierarchical structure. The overall procedure is described by algorithm A.

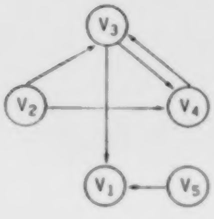

Fig. 3. A directed graph composed of each directed relationship of Figure 2.

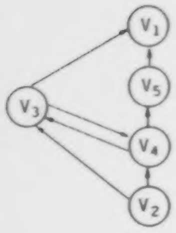

Fig. 4. The hierarchical structure deducted from Figure 3.

Algorithm A:

Input: Teaching content S

Output: Hierarchical structure H

Step 1: {Generate teaching elements} Divide teaching content S to teaching elements $V_{1,} V_{2,\ldots} V_n$.

Step 2: {Decide the directed connections between teaching elements} Establish the relationships among the teaching elements according to logic, experience, subject, intuition as $V_i \to V_{j,}$ $i = 1,2,\ldots,n$, and $i \neq j$.

Step 3: {Show the relationships among the teaching elements by a graph} The relationship among teaching elements is exhibited by graph G. Set $LEVEL = 1$, $ELEMENT = \{V_{1,} V_{2,\ldots,} V_n\}$, $REMOVE = \phi$, $G_{LEVEL} = G$.

Step 4: {Establish the hierarchical structure} According to graph $G_{LEVEL,}$ if $R(V_i) = R(V_i) \cap A(V_i)$, then the teaching element V_i is located in LEVEL level of hierarchical structure H and $REMOVE = REMOVE \cup \{V_i\}$

Step 5: {Condition test} Remove the vertex and edge belonging to REMOVE and obtain the resulting graph $G_{LEVEL+1.}$ Then, $LEVEL = LEVEL + 1$ and $ELEMENT = ELEMENT - REMOVE$. Set $REMOVE = \phi$. If $ELEMENT \neq \phi$, then repeat step 4.

Step 6: {Establish the hierarchical structure of teaching material} Establish the edge of hierarchical structure H between each vertex according to graph G. Then H is the final structure of the courseware.

Step 7: {Stop}

III. The Evaluation of Courseware

According to the discussion above, we know that the courseware basically is a hierarchical structrue. When the courseware is executed, there are usually initializing steps, such as the log-in script, opening the data file and so on. These steps don't belong to the teaching scope of the courseware. We call these initializing steps as the initial state (abbreviated as S_i). In the same way, the courseware also has the final state (abbreviated as S_f) as the terminating steps. Putting S_i and S_f into figure 4, we get figure 5. Consider some teaching elements $V_{i,}$ the user can talk with the courseware through man-machine interface. The courseware executes to user response so that the user can retry or transfer to another teaching element $V_{j,}$ which has a relationship with V_i. In figure 5, for example, the user is on the teaching element V_2, through the man-machine interaction and the courseware responds to descide whether to stay at V_2 or to transfer to V_3 or V_4. In the same time, the courseware can output some hints to the user (in text, sound, or graph) to show the current state.

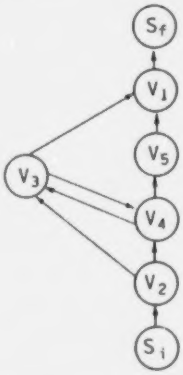

Fig. 5. A CAI courseware can be represented by hierarchical structure, initial state S_i and final state S_f.

The teaching element of the courseware is a finite set. The symbol set of the man-machine interface is also a finite set. The output that the courseware responds to is also a finite set. We can express the courseware as a finite state machine.

Definition 1: The courseware can be defined as a finite state machine:

$CAI = [S, I, O, F_s, F_o]$,

where,

S: the set of the finite teaching elements,

I: the set of the finite input symbols,

O: the set of the finite output responses,

F_s: the transfer function among the teaching elements is $F_s : S \times I \to S$,

F_o: the output response function is $F_o : S \times I \to O$.

From another point of view, we can simplify the structure of the courseware to be a directed graph without considering what the user input and what the courseware response are.

Definition 2: Simplified CAI courseware can be represented as a directed graph

$SCAI=[V,A,M]$,
where,
V:the set of teaching elements,
A: the directed relationships among the teaching elements $V_i V_j$ (Arc, Edge),
M: the function between the directed relationships among the teaching elements. It is denoted by $M:A \rightarrow V \times V$.

Since the function M is a one-to-one function, SCAI is a simple graph. From the quantity measurement point of view, through the man-machine interface, the output response by the courseware and the input contents by the user can be ignored, because these factors are related to the representation of the courseware itself. Therefore, we can take the structure of SCAI to be used in the quantity measurement rule of the courseware.

Definition 3: The attribute A_{V1} and A_{V2} in the courseware [V,A,M] are defined as follows:

$A_{V1}=[F_j, T_j, R_j, N_j, U_j]$,
where,
F_j = the frequency user j uses the teaching element,
T_j = the time user j spends using the teaching element,
R_j = the rumber of retries user j uses the teaching element,
N_j = the score user j receives on the teaching element,
U_j = the success and failure of user j using the teaching element.
A_{V2} = [S-Score, S-Time],
where,
S-Score: the specified limit of the highest score in the teaching element,
S-Time: The specified limit of the time in the teaching element.

So, $A_{V1}(V_i, K)=[F_j(K), T_j(V_i, F_j(k)), R_j(V_i, F_j(k)), N_j(V_i, F_j(k)), U_j(V_i, F_j(k))]$ stands for the attribute of the kth teaching element V_i that is within the learning path of user j. $F_j(K)$ is the times that the user uses teaching element V_i. As for $A_{V2}(V_i)$ = [S-Score(V_i), T-Time(V_i)] represents the upper bound of the learning times and scores in teaching element V_i.

Considering the directed graph of SCAI, the user begins from the state S_i into the courseware and wants to arrive at S_f as soon as possible. But there is not only one path from S_i as an initial state to S_f as a final state. If the user passes n teaching elements $V_1, V_2 \ldots V_n$ from S_i to arrive at S_f, we take $(S_i, V_1, V_2, \ldots, V_n, S_f)$ to represent the learning path.

Definition 4: The leaning path of the user j in the CAI system is:

$P_j=(S_i, V_1, V_2, \ldots, V_n, S_f)$,
which represents the user j begining from state S_i, through $V_1, \ldots, V_n$ teaching element, to arrive at S_f of the courseware.

Definition 5: The shortest learning path of the courseware is as follows:

If the weight function C corresponding to every edge of the directed graph that is related to the courseware and the following conditions are satisfied:
(1) $C(V_i, V_j)=\infty$ means. NOT. $(V_i \rightarrow V_j)$,
(2) $C(V_i, V_k)=C(V_i, V_j)+C(V_i, V_k)$ stands for $(V_i \rightarrow V_j) \cap (V_j \rightarrow V_k)$,
then the shortest learning path is $P_j(S_i, V_1, V_2, \ldots, V_n, S_f)$, and the resulting value of $C(S_i, V_1)+\sum_{i=1}^{n-1} C(V_i, V_{i+1})+C(V_n, S_f)$ is the minimum.

Dijkstra (1959) proposed a way to find the weignt sum of the shortest path by undirected graph. We provied an algorithm in the following paragraph designed basically by his method, and this algorithm can find the shortest path of the directed graph and the sum of the weight of the shortest path.

Algorithm B:

Input: Directed graph $G=[V,A,M]$ and weight function C.

Output: Under the weight function C, the shortest path P from state S_i to state S_f and the sum of weight W.

```
Step 1: $S \leftarrow \{S_i\}$, $D(S_i) \leftarrow O$.
Step 2: To each $\mu \in V-\{S_i\}$ do the following action:
        $D(u) \leftarrow C(S_i, u)$, $J(u) \leftarrow S_i$.
Step 3: If $S \neq V$ do the following action:
        (1) within $V - S$, chose one u to make $D(u)$ minimum,
        (2) $S \leftarrow S \cup \{u\}$,
        (3) to each $u' \in (V - S)$, if $D(u') > D(u) + C(u,u')$,
                then $D(u') \leftarrow D(u) + C(u,u')$, $J(u') \leftarrow u$.
Step 4: If $S \neq S_f$ then go back to step 3.
Step 5: $P \leftarrow \{S_f\}$, $u \leftarrow S_f$.
Step 6: $P \leftarrow J(u) + P$, $u = J(u)$.
        If $u \neq S_i$ repeat step 6.
Step 7: Let $W = D(S_f)$. Therefore, P is the shortest path
        from $S_i$ to $S_f$ and W is the sum of weight of the
        shortest path P.
Stpe 8: Stop.
```

Now, we discuss about the quantity measurement rule of the courseware from four different point of view.

(1) The length of leaning path: It's the length that the user finishs the courseware. From the definition the learning path is

$$P_j = (V_{e(j,1)}, V_{e(j,2)}, \cdots, V_{e(j,g(j))}), \tag{1}$$

where g(j) is the number of the teaching elements in the learning path of the user j and $V_{e(j,k)}$ is the kth teaching element within the learning path of the user j. So $V_{e(j,1)} = S_i$, $V_{e(j,g(j))} = S_f$, and the average length of the learning path is

$$\sum_{j=1}^{m} g(j)/m, \tag{2}$$

where m is the number of the user.

(2) Learning time: the time that the user finishes the courseware. From the definition, the learning time is

$$\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i)), \tag{3}$$

where T_j is the time that the user j spends using the teaching element F_j times. So the average of the learning time is

$$\sum_{j=1}^{m}\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/(\text{S-Time}(V_{e(j,i)})g(j)m), \tag{4}$$

and the learning time rate for the user j is

$$\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/(\text{S-Time}(V_{e(j,i)})g(j)). \tag{5}$$

(3) Learning achievement: the score that the user finishes the courseware to get. From the definition the learning achievement is

$$\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i)), \tag{6}$$

where N_j is the score that the user gets using the teaching element F_j times. So the average of the learning achievement is

$$\sum_{j=1}^{m}\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i))/(\text{S-Score}(V_{e(j,i)})g(j)m), \tag{7}$$

and the learning achievement rate for the user j is

$$\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i))/(\text{S-Score}(V_{e(j,i)})g(j)). \tag{8}$$

(4) Success rate: the completeness of the user finishing the courseware. From the definition the success rate is

$$\sum_{i=1}^{g(j)} U_j(V_{e(j,i)}, F_j(i))/g(j), \tag{9}$$

where U_j is the success rate that the user gets using the teaching element F_j times. So the average of the leaning success rate is

$$\sum_{j=1}^{m}\sum_{i=1}^{g(j)} U_j(V_{e(j,i)}, F_j(i))/g(j)m). \tag{10}$$

All these are from the user's point of view to discuss the macro measurement in the CAI system. From the micro measurement, point of view, we get the measurement rule as follows:

(1) The scatter of the learning path: the frequency that the user uses some teaching element V_i. Form the definition we get

$$\sum_{j=1}^{m} F'_j(V_i)/m, \tag{11}$$

where,

$$F'_j(V_i) = \begin{cases} \sum_{k=1}^{g(j)} F_j(k), & \text{if } e(j,k)=i; \\ 0, & \text{if } e(j,k) \neq i, k = 1, 2, \cdots, g(j). \end{cases} \tag{12}$$

(2) The spent time rate of the teaching element: the time rate spent by the user while using the teaching element V_i. From the definition we get

$$\sum_{j=1}^{m} T'_j(V_i)/m'(V_i), \tag{13}$$

where,

$$T'_j(V_i) = \begin{cases} \sum_{k=1}^{g(j)} T_j(V_i, F_j(k))/\text{S-Time}(V_i), \\ \qquad\qquad \text{if } e(j,k)=i; \\ 0, \quad \text{if } e(j,k) \neq i, k = 1, 2, \cdots, g(j); \end{cases} \tag{14}$$

$$m'(V_i) = \begin{cases} \sum_{j=1}^{m} 1, & \text{if } T'_j(V_i) \neq 0; \\ 1, & \text{if } T'_j(V_i) = 0, j = 1, 2, \cdots, m. \end{cases} \tag{15}$$

(3) The score rate of the teaching element: the score rate that the user gets while using the teaching element V_i. From definition the score rate of the

teaching element is

$$\sum_{j=1}^{m} N'_j(V_i)/m'(V_i), \tag{16}$$

where,

$$N'_j(V_i) = \begin{cases} \sum_{k=1}^{g(j)} N_j(V_i, F_j(k))/\text{S-Score}(V_i)F'_j(V_i), \\ \qquad\qquad \text{if } e(j,k)=i; \\ 0, \ \text{if } e(j,k) \neq i, k = 1, 2, \cdots, g(j). \end{cases} \tag{17}$$

(4) The success rate of the teaching element: the success rate that the user gets while using the teaching element V_i. From the definition the success rate is

$$\sum_{j=1}^{m} U'_j(V_i)/m'(V_i), \tag{18}$$

$$U'_j(V_i) = \begin{cases} \sum_{k=1}^{g(j)} U_j(V_i, F_j(k))/F'_j(V_i), \\ \qquad\qquad \text{if } e(j,k)=i; \\ 0, \ \text{if } e(j,k) \neq i, k = 1, 2, \cdots, g(j). \end{cases} \tag{19}$$

According to the rules described from equation (1) through (19), we can make some quantity measurements on both the used courseware and the record of behavior of the user. Hence, we present a quantity measurement of user's learning path.

First we select a spent time attribute as an example, which is denoted by $AT(V_k V_l)$. It represents a weight function concerning spent time as a function of the relationship between teaching elements V_k and V_l of a used courseware, which can be derived as follows:

$$AT(V_k V_e) = \sum_{j=1}^{m} AT'_j(V_k V_l),$$

where $AT'_j(V_k V_l) = \sum_{i=2}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/S-\text{Time}(V_{e(j,i)})$, i must satisfy that $e(j,i-1)=k$ and $e(j,i)=l$. We can obtain the shortest learning path of spent time by means of algorithm B in which the weight function C is assigned by the spent time attribute $AT(V_k V_l)$ that we present here. Similarily, if we select some attributes which can be expressed in terms of equation (1) through (19), then we have the results of quantity measurement.

IV. The Strategy of the Quantity Measurement Rule

In this section, we will discuss the strategy of the quantity measurement rule of the courseware from the two aforementioned points of view. The first point is to discuss the user's learning behavior by the meaurement rule from (1) to (10) as described above. The second point is to do the evaluation of the courseware itself by the measurement rule from (11) to (19). Further more, we will study the feature of the courseware in the measurement rule from (11) to (19).

Because the courseware is a hierarchical directed graph, the minimum path length of the courseware from S_i to S_f should be the level of the hierarchical directed graph subtracting 2(S_i and S_f). The shorter the learning path obtained by the measurement rule (1), the better the reasoning ability of the user. The learning time rate obtainted by the meaurement rule (5) shows the solving ability of the user. The less time spent, the better the user's reasoning ability. The user's achievement rate obtained by the measurement rule (8) represents the user's degree of understanding of the courseware. The more intelligent the user is, the higher achievement rate he gets. The learning success rate obtainted by the measurement rule (9) shows the completeness of the learning path of the user. According to these features we propose the following quantity measurement strategy:

(1) The quantity measurement of the user's reasoning ability is

$$\log\left(\frac{\text{the average of the learning path (2)}}{\text{the length of the user's learning path (1)}}\right) = \log\left(\frac{\sum_{i=1}^{m} g(j)}{g(j)m}\right) \tag{20}$$

(2) The quantity measurement of the user's answering ability is

$$\log\left(\frac{\text{the user's learning success rate (9)}}{\text{the average of learning success rate (10)}} \times \frac{\text{the average of the learning time rate (4)}}{\text{the user's learning time rate (5)}}\right)$$

$$= \log\left(\frac{\sum_{i=1}^{m} U_j(V_{e(j,i)}, F_j(i))}{\sum_{j=1}^{m}\sum_{i=1}^{g(j)} U_j(V_{e(j,i)}, F_j(i))/g(j)} \times \frac{\sum_{j=1}^{m}\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/(\text{S-Time}(V_{e(j,i)})g(j)m))}{\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/\text{S-Time}(V_{e(j,i)})}\right) \tag{21}$$

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(3) The quantity measurement of the user's learning achievement ability is

$$log\left(\frac{\text{the learning achievement rate of the user (8)}}{\text{the average of the learning achievement rate (7)}}\right)$$

$$= log\left(\frac{\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i))/(\text{S-Score}(V_{e(j,i)})g(j))}{\sum_{j=1}^{m}\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i))/(\text{S-Score}(V_{e(j,i)})g(j)m)}\right) \quad (22)$$

From the measurement rule (11) to (19), we can measure the performance of the utilized teaching elements of the courseware. It is worth while for the courseware designer to spend more time to develope a highly utilized teaching element. It is expedient to be able to refine a given courseware. For example, we can refine a highly time-consuming teaching element into several smaller teaching elements so that the user can learn it more fluently. In addition, the score rate is related to the clearness of the teaching content, and the success rate of the teaching element offers a quantitative measurement as to whether the content is easy or not. We can induct the following evaluation strategy for the courseware:

(1) The quantity measurement of the development of the teaching element is

$$log\left(\frac{\text{the utilisation of teaching element (11)}}{\text{the average of utilisation (2)}}\right)$$

$$= log\left(\frac{e' \sum_{j=1}^{m} F_j'(V_i)}{\sum_{j=1}^{m} g(j)}\right), \quad (23)$$

where e′ is the number of the teaching element.

(2) The quantity measurement of the fineness of the teaching elememt is

$$log\left(\frac{\text{the time consume rate of teaching element (13)}}{\text{the average of learning time (4)}}\right)$$

$$= log\left(\frac{m \sum_{j=1}^{m} T_j'(V_i)}{m'(V_i) \sum_{j=1}^{m}\sum_{i=1}^{g(j)} T_j(V_{e(j,i)}, F_j(i))/(\text{S-Time}(V_{e(j,i)})g(j))}\right) \cdot (24)$$

(3) The quantity measurement of the effectiveness of the teaching element is

$$log\left(\frac{\text{the score rate of teaching element (16)}}{\text{the average of the learning achievement (7)}}\right)$$

$$= log\left(\frac{m \sum_{j=1}^{m} N_j'(V_i)}{m'(V_i) \sum_{j=1}^{m}\sum_{i=1}^{g(j)} N_j(V_{e(j,i)}, F_j(i))/(\text{S-Score}(V_{e(j,i)})g(j))}\right) \cdot (25)$$

(4) The quantity measurement of the diffculty level of the teaching element is

$$log\left(\frac{\text{the success rate of teaching element (18)}}{\text{the average of learning success rate (10)}}\right)$$

$$= log\left(\frac{m \sum_{j=1}^{m} U_j'(V_i)}{m'(V_i) \sum_{j=1}^{m}\sum_{i=1}^{g(j)} U_j(V_{e(j,i)}, F_j(i))/g(j))}\right) \quad (26)$$

In figure 6, the CAI can be divided into subsystems composed of the courseware editing subsystem, courseware base subsystem, courseware executing subsystem, and flow control subsystem. If we want the CAI system with the quantity measurement ability, we need to add the quantity measurement subsystem. In summary, based on the proposed strategy, the quantity measurement subsystem has the following basic functions:

(1) Build the hierarchical structure: directed graph (algorithm A, definition 2).

(2) Record the learning path of the user (definition 4).

(3) Save the attribute information of each teaching element (definition 3).

(4) Evaluate the performance of the teaching element and users behavior ((1) to (19)).

(5) Measure the learning achievement of the user ((20) to (22)).

(6) Measure the effectiveness of the courseware ((23) to (26)).

(7) Analyze the shortest learning path of the courseware (algorithm B).

Function (1) is a preparation step. Function (2) and (3) is a data collection facility implemented while the user interacts with the courseware. Function (4) is to calculate the measurement rule. Function (5), (6) and (7) are to do the quantity measurement after the user finishes using the courseware.

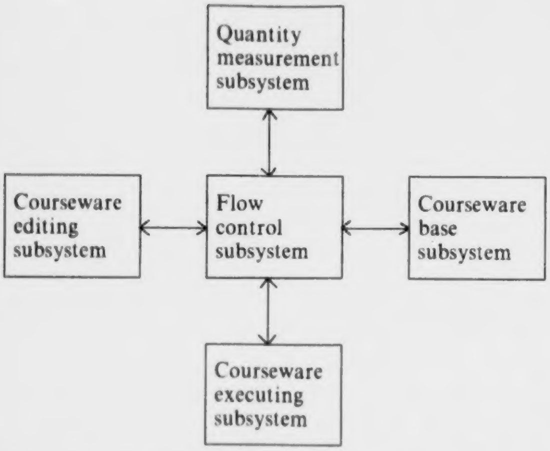
Quantity measurement subsystem
Courseware editing subsystem
Flow control subsystem
Courseware base subsystem
Courseware executing subsystem

Fig. 6. A CAI system composed of five subsystems

V. Conclusion

Today, CAI courseware is used by people widely and the quantitative measurement strategy to evaluate the courseware itself and the user's learning behavior is becoming more and more important. In this paper, we have proposed an evaluation strategy to do the quantitative measurements to meet this goal. The evaluation strategy is suitable to do the quantity measurements for the courseware itself and the learning behavior of the user. Our research goal in the future is to overcome the limit of the static flow control of the courseware and how to develope quantity measurements with dynamic propenties for intelligent courseware.

References

Chen, T.S. (1986). An analysis of the application of S-P chart in learning diagnosis and the level of appreciaton received. *Guidance Journal*, National Taiwan College of Education No. 9, 275-311.

Chimura, H. (1984). Computer-assisted analysis and determination of instructional sequences. *Proceedings of EdCompCon-84*, IEEE Computer Society.

Dijkstra, E.W. (1959). A note on two problem in connexion with graphs. *Numerische Mathematik*, 269-271.

Sato, T. (1973). Instructional data processing approach to computer managed instruction. *NEC Research & Development*, No. 29, 38-49.

Sato, T. (1984). *The state of art on S-P analysis activities in Japan*. C & C System Research Lab., NEC Corp.

Sato, T. (1986). *The S-P chart analysis*. C & C System Research Lab., NEC Corp.

Takeya, M. and Sato, T. (1974). Construction and evaluation methods for instructional programs in CAI. *NEC Research & Development*, No. 34, 31-38.

CAI課程軟體量化評估資訊系統之設計

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摘要

電腦輔助教學課程軟體的使用，有兩個重要的資料爲教師及課程設計者所忽略，一個是當課程軟體爲學習者使用時所留下的資料，如研讀某一單元所費的時間、接受測驗重複使用的次數等，皆可作爲評估該課程軟體優劣之用；另一個是當學習者使用課程軟體時，在學習過程中的學習記錄，可做爲評估學習者的學習成效之用。

在本篇論文裡，我們以圖形理論爲基礎，定義課程軟體的教學內容的階層式網路結構爲一具有方向性的圖形資料結構，並且賦予屬性給課程軟體裡的教學單元和教學單元間的主從關聯。以這兩個屬性爲基礎，我們將提出新的評估準則，作爲課程軟體的定量評估的策略，利用這一定量評估策略，我們將更進一步探討電腦輔助教學量化資訊系統的設計原理。同時，這個量化資訊系統可提供做爲課程軟體管理及評估教學之用。

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A Study of Conceptual Development of Calculus

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ABSTRACT

This study surveyed college students' understanding of pre-calculus and calculus. Written test items were developed. About 1200 students attended the tests. By applying factor analysis and multiple regression analysis on data collected from these tests, some structures of students' conceptual development of understanding calculus were constructed.

Key words: differential and integral calculus, conceptual development

I. Introduction

Differential and Integral Calculus is a basic course in college mathematics, and is closely relied on school mathematics. Adopting the principle of developing written test items of the research project "The Concepts in Secondary Mathematics and Science" (Hart, 1981), and the idea of A. Orton in the study on "Student's Understanding of Calculus" (Orton, 1983a, 1983b), I analysed the basic concepts of school mathematics and calculus, and developed written tests, to examine students' conceptual development of calculus. By analysing the results of the tests, I obtained detailed data concerning different degrees of understanding attained by the students, and constructed structures of conceptual development of calculus.

II. Methods

The items of the written tests covered the following three catagories:

1. High school mathematics that are relevent to the learning of calculus, such as line, curve, rate of change, reflection, translation, contraction and magnification, polynomial, partial fraction, trigonometry, absolute value, inequality, tangent line and free fall.
2. Basic concepts of differential calculus, such as limit of sequence, limit of function, continuity, derivative, graph of derivative, motion of projectile, extremum, point of inflection, differential, proof of continuity and proof of limit.
3. Basic concepts of integral calculus, such as area, definition of integral, calculation of integral, arc length, volume, fundamental theorem of calculus, and graph of integral.

Written tests were given to 300-500 calculus students of different majors from different universities each year for three years. The test papers were graded. Means and standard deviations of the scores were found. Interviews with a small number of students were held, to check the answers of written tests. Factor analysis was applied to the data obtained, and multiple regression analysis was carried out on key items chosen from the concept items of the written tests.

Adopting the idea of A. Orton (1983a, 1983b), that was based on Piaget's stage theory of conceptual development (Inhelder and Piaget, 1958), measures of conceptual development were assigned to tested items of concepts in calculus. By cross-tabulation and cluster analysis of data, ranks of difficulty were also determined for items in each test.

The difference between the results of the second and the third years was investigated by t-test of the score mean of each item in tests of the third year with that of the corresponding item in tests of the second year.

To observe the effectiveness of the tests, the coefficients of correlation of scores of exams of a calculus class with scores of the given written test were found. Coefficients of reliability for the results of the written tests of the class were also calculated. The study was carried out during three years:

1. In the first year (August 1985 — July 1986) a sample of 310 calculus students of different majors from three universities was chosen. Three written tests were given in this year. The assessments were in a four-point scale (0,1,2,3) for Test I, and in a five-point scale (0,1,2,3,4) for Test II and III. Interviews with ten students were held, to check the answers by the students in the written tests. Mean scores and standard deviations of the items were found and factor analysis was applied to scores of the written tests taken by the students.
2. In the second year (August 1986 — July 1987) the sample was composed of 351 students of different majors from three universities. The test tools were revised. The students were given written tests three times. The assessments were in a five-point scale (0,1,2,3,4). Interviews were also held with ten students. Histograms of scores of the tests were made, mean scores and standard deviations of items were found. Factor analysis and multiple regression were carried out on the data collected by the written tests.
3. In the third year (August 1987 — July 1988) the sample was composed of 543 students of different majors from five universities. The test tools were revised and items for two given written tests were developed. The students were given written tests twice this year. Again, ten students were interviewed, to check the answers of the written tests. Statistical analyses were carried out on the data collected by the written test, such as histograms, mean scores, standard deviations, factor analysis, multiple regression, crosstabulation, cluster analysis and t-test.

III. Results

The study of the first two years was considered as a pilot study. We improved tools and methods of the study for the third year accordingly. Two written test tools of 20 items each were developed (see Appendices 1 and 2).

For the third year 1987/88, histograms of scores attained by students are shown in Figures 1 and 2. Mean scores and standard deviations of items are listed in Tables 1 and 2.

Four principal factors of concepts of fundamental mathematics and elementary concepts in calculus were extracted by factor analysis. By observing the items included in each factor, I could annotate the 4 factors as synthetic analysis, basic operation, discussion of graph and one-step analysis respectively (see Table 3,4). And five principal factors of basic concepts of calculus were extracted. They could be annotated as synthetic analysis, understanding and reasoning, basic operation, discussion of graph and one-step analysis (see Table 5,6).

I chose 3 key items of concepts in fundamental school mathematics and 7 key items of elementary concepts in calculus, and carried on multiple regression. The results are listed in Tables 7 and 8. In these Tables one could see how the key items with other items are related.

Adopting the idea of Orton (1983a,1983b), measures of conceptual development assigned to tested items of concepts in calculus were decided by analysis of the data of the tests taken by the students and by discussions with five collegues, experienced calculus teachers.

By pairwise crosstabulation of scores of items, we could arrange the items in partial order according to the degrees of difficulty. For example, Item 1 is easier than Item 2 for Test 1, and Item 1 is more difficult than Item 2 for Test 2, as shown in Table 9. Cluster analysis of scores of items of each test put items of same order of difficulty together into groups (Table 10). According to the combination of the results of crosstabulation and cluster analysis, ranks of difficulty for items were determined. Measures of conceptual development and ranks of difficulty of items are listed in Table 11 and 12. The measure of conceptual development and rank of difficulty of each item are quite compatible. For example, in Table 11, Item 1, average rate of change of curve, is assigned measure of 9 points and its rank is II, both in the middle. And Item 8, stretching and contraction of polygonal line, is assigned 15 points and its rank is III, both in the top.

To compare the score means of each item of tests in the second year and that in the third year, I carried out t-test and found that the difference of score means of items in each test between these two years were of no signifance or not very large. The results of t-test of the first two items in test 1 are shown as examples in Table 13. In this table, we see that the difference of score means of item 1 between two years is of no significance and that of item 2 is small.

To see how the scores of tests on concepts of calculus and the scores of the Calculus course were to be correlated, we calculated coefficients of correlation of scores of tests with Calculus scores for one class of 65 students majoring in Geology in

1986/87 and one class of 47 students majoring in Industrial and Business Management in 1987/88. These are all bigger than 0.3 and of significance (Table 14). Using the data of the same class in 1987/88, we also found the coefficients of reliability defined by C. Hoyt (see Chien,1989) as follows:

$$\begin{cases} r_H = 0.86 \text{ for Test 1} \\ r_H = 0.73 \text{ for Test 2} \end{cases}$$

IV. Conclusions

Tools for written tests

The performances on written tests taken by students of different majors from different universities in these three years were quite consistent. And the scores of the students on those tests were found to be compatible with their scores in Calculus course. We would suggest that the tools for two written tests could be used to examine students' conceptual development in calculus.

Interviews

By interviews with students, we checked the data of written tests, and found that they were reasonable and could reveal situations of students' understanding of calculus to some extent.

Factor Analysis

According to the results of factor analysis, we find that students have quite good understanding of fundamental concepts in Differential and Integral Calculus, such as rate of change, finding limit, differentiation, extreme value, sketching graph, and integration, but have difficulty in reasoning and synthetic analysis, such as the proof of limit, graph of integral function, and differentiation of piecewise defined function. Therefore, in the development of the concepts in calculus, we suggest that we should strengthen students' ability in verbal representation, reasoning and synthetic analysis.

Multiple Regression

In the results of multiple regression, we found the correlations of the key items with related items. According to these, we suggest that some of the related items would be used as reference examples in Calculus course, such as:

F08	Magnification of polygonal line
F19	Tangent point of parabola
F20	Area of parabolic region
C07	Derivative of piecewise defined function
C08	Graph of derivative
C20	Graph of integral

Measures of Conceptual Development and Ranks of Difficulty

Measures of conceptual development and ranks of difficulty are quite compatible; we could make the following correspondence:

Measure	Rank
6, 7, 8	I
9, 10, 11	II
12, 13, 14, 15	III

According to the ranks, we find that most students experience difficulty in solving problems in transformations of reflection and stretching of polygonal line. (Items F6 and F8 of rank III). Some students can not solve inequality involving absolute value of one unknown (Item F16 of rank III). Only a few students can grasp the idea of the definition of limit given by the ϵ—δ method, and make use of it (Item C13 of rank III). Students in general can carry on partial fractions and synthetic division of polynomials (Items F9 and F15 of rank I) and can find limits of number sequences (Item C2 of rank I).

Acknowledgement

I am very grateful to Prof. Fou-Lai Lin of National Taiwan Normal University and Prof. Men-Fon Huang of National Taiwan University for their valuable suggestions on this study.

References

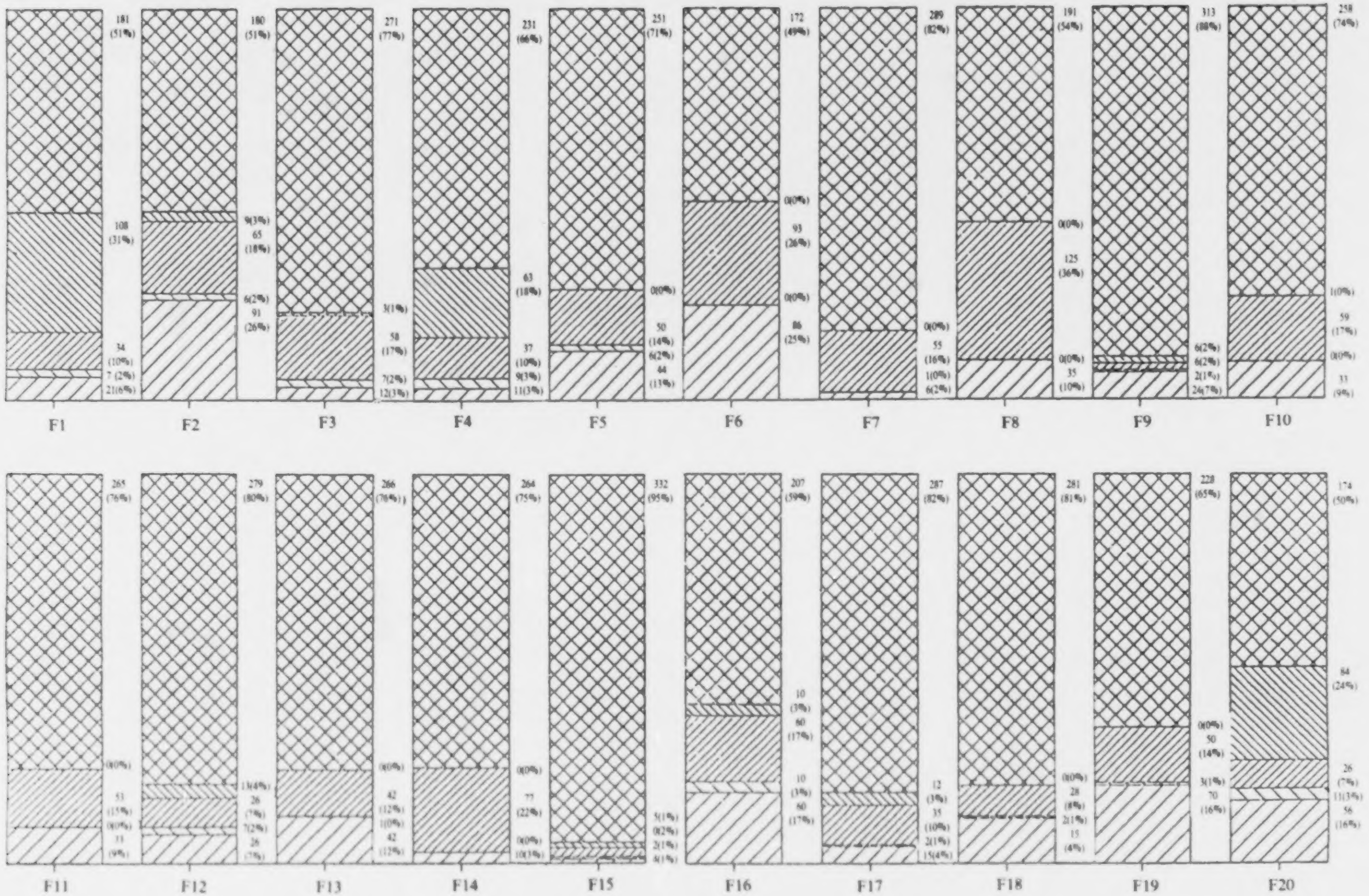
Chien M.F. (1989). *Psychological testing and statistical methods* (in Chinese), Psycho Publish Co..

Hart K.M. (ed.) (1981). *Children's understanding of mathematics.* London: John Murray.

Inhelder B. and Piaget J.(1958). *The growth of logical thinking from childhood to adolescence.* Basic Books.

Orton A. (1983a). Student's understanding of differentiation, *Educational Studies in Math., 14,* 235-250.

Orton A. (1983b). Student's understanding of integration. *Educational Studies in Math. 14,* 1-18.



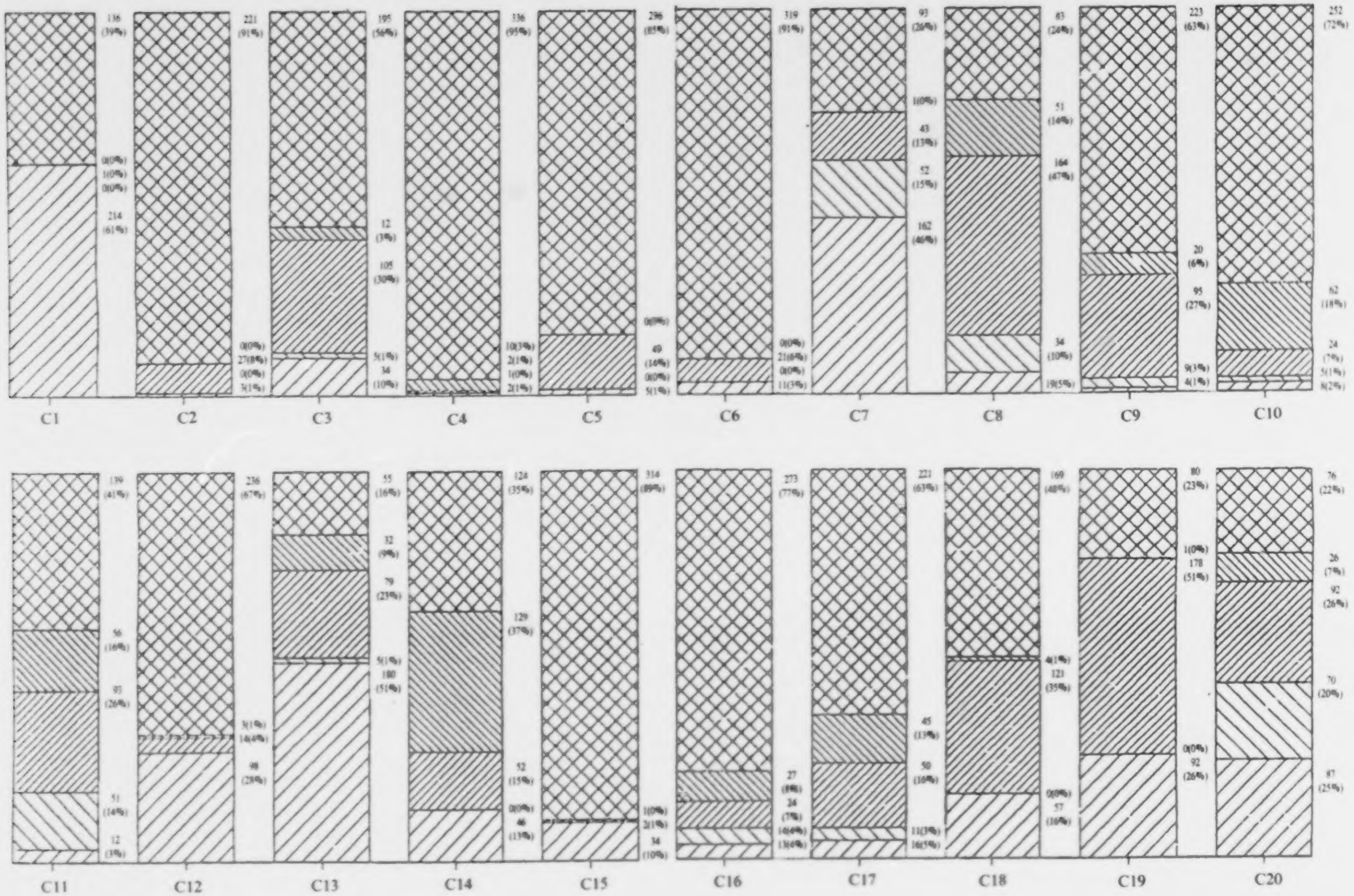
Histogram of Scores

Fig. 1. Test 1 on Concepts of Fundamental School Mathematics
Academic year 1987/88**

Nos. of students: 351*

**	▨	▨	▨	▨	▨
	0	1	2	3	4

*Number of students that took both Test 1 and Test 2.



Histogram of Scores
Fig. 2. Test 2 on Concepts of Calculus
Academic year 1987/88**

Nos. of students: 351*

** ▨ ▧ ▩ ▤ ▦
0 1 2 3 4

*Number of students that took both Test 1 and Test 2.

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Table 1. Mean Scores and Standard Deviations of the test on Fundamental School Mathematics — 1987/88

(Nos. of students: 543)

No.	Item	Mean	S.D.
F01	Average rate of change of curve	3.10497	1.19733
F02	Equation of line for given angle	2.39042	1.74014
F03	Roots and horizontal tangent lines	3.39227	1.11137
F04	Intersections of curve and line	3.30571	1.09616
F05	Length of tangent lines	3.01473	1.48540
F06	Reflection of polygonal lines	2.41989	1.62814
F07	Reflection and trnaslation of curves	3.49724	0.98302
F08	Magnification of polygonal line	2.75138	1.38883
F09	Partial fractions	3.53959	1.21863
F10	Addition formula of sine	3.20994	1.37858
F11	Graph of absolute value function	3.15285	1.42352
F12	Trigonometric equation	3.36648	1.28148
F13	Division of polynomials	3.20810	1.42039
F14	Deformation of polynomials	3.30939	1.12832
F15	Synthetic division	3.84162	0.67695
F16	Inequality of absolute values	2.62247	1.66669
F17	Free fall	3.56169	1.02881
F18	Tangent line of parabola	3.20810	1.47143
F19	Tangent point of parabola	2.67403	1.69724
F20	Area of parabolic region	2.76796	1.49215

Table 2. Mean Scores and Standard Deviations of the test on Concepts of Calculus — 1987/88

(Nos. of students: 483)

No.	Item	Mean	S.D.
C01	Sequence of polygonal lines	1.44513	1.92132
C02	Limits of number sequences	3.79296	0.67452
C03	Continuity of function	2.78261	1.41581
C04	Rate of of change of line	3.86128	0.53061
C05	Rate of change of parabola	3.57971	0.92418
C06	Differentiation by definition	3.66874	0.95869
C07	Derivative of piecewise defined function	1.44928	1.66705
C08	Graph of derivative	2.33333	1.19762
C09	Motion of projectile	3.18219	1.11382
C10	Cubic curve	3.44306	1.01154
C11	Application of differential	2.66253	1.22897
C12	Proof of continuity	2.59213	1.86174
C13	Proof of limit	1.25880	1.51524
C14	Area of circle	2.69358	1.33003
C15	Area of trapezoid	3.49689	1.31599
C16	Definition of integral	3.36025	1.20624
C17	Calculation of integral	3.20911	1.14859
C18	Application of integral	2.43478	1.54376
C19	Fundamental theorem of calculus	1.86957	1.42356
C20	Graph of integral	1.75155	1.48728

Table 3. Factor Analysis of Fundamental School Mathematics — 1987/88

(Nos. of students: 543)

Factor	Eigen value	Percentage of variance	No.	Item
I Synthetic Analysis	5.64849	28.2	20	Area of parabolic region
			18	Tangent line of parabola
			19	Tangent point of parabola
			3	Roots and horizontal tangent lines
			4	Intersections of curve and line
			16	Inequality of absolute values
II Basic Operation	1.29532	6.5	15	Synthetic division
			14	Deformation of polynomials
			9	Partial fractions
			10	Additon formula of sine
			5	Length of tangent lines
			7	Reflection and translation of curves
			13	Division of polynomials
III Graph Discussion	1.20662	6.0	6	Reflection of polygonal line
			8	Magnification of polygonal line
			11	Graph of absolute value function
IV One-Step Analysis	1.02785	5.1	17	Free fall
			1	Average rate of change of curve
			12	Trigonometric equation
			2	Equation of line for given angle
	Total	45.9		

MINEIGEN (1.0)
Kaiser-Mayer-Olkin Measure of Sampling Adequacy = .91552
Bartlett Test of Sphericity = 2411.3104, Significance = .00000

Table 4. Factor Loading of Fundamental School Mathematics — 1987/88

(Nos. of students: 543)

No. of Item	Factor I f_1	Factor II f_2	Factor III f_3	Factor IV f_4	Communality $h^2 = \Sigma f_i^2$
1	.23006	—.06969	.18440	.63432	.49414
2	.28560	.07083	.28557	.34695	.28851
3	.53777	.24640	.22304	.25402	.46418
4	.41695	.26542	.28908	.13030	.34484
5	.40424	.41076	.05608	.24704	.39630
6	.09793	—.09893	.78717	.08910	.64696
7	.17902	.38944	.37477	.30373	.41641
8	.12790	.16093	.73990	.08960	.59774
9	.05885	.58970	—.06229	.07411	.36058
10	—.13892	.42613	.00946	.40264	.36310
11	.20167	.30283	.48926	.26574	.44237
12	.32460	.36822	.20636	.47191	.50624
13	.30053	.33854	.28783	—.02996	.28867
14	.22310	.60144	.29151	—.12323	.51167
15	.13473	.61263	.09010	.09349	.41033
16	.34515	.32196	.11118	.08267	.24198
17	.22009	.11812	.02625	.71869	.57960
18	.74627	.10518	.09149	.12944	.59310
19	.74515	.10912	.16797	.10541	.60648
20	.75577	.02621	.05752	.22339	.62508
				Total	9.17828

Table 5. Factor Analysis of Concepts in Calculus — 1987/88

(Nos. of students: 483)

Factor	Eigen value	Percentage of variance	No.	Item
I Synthetic Analysis	4.95751	24.8	5	Rate of change of parabola
			8	Graph of derivative
			20	Graph of integral
			9	Motion of projectile
			14	Area of circle
			4	Rate of change of line
			3	Continuity of function
II Reasoning	1.37898	6.9	13	Proof of limit
			12	Proof of continuity
			7	Derivative of piecewise defined function
			1	Sequence of polygonal lines
III Basic Operation	1.19838	6.0	18	Application of Integral
			17	Calculation of integral
			11	Application of differential
			19	Fundamental theorem of calculus
IV Graph Discussion	1.07824	5.4	6	Differentiation by definition
			10	Cubic curve
			16	Definition of integral
V One-Step Analysis	1.04131	5.2	2	Limits of number sequences
			15	Area of Trapezoid
	Total	48.3		

MINEIGEN (1.0)
Kaiser-Mayer-Olkin Measure of Sampling Adequacy = .87194
Bartlett Test of Sphericity = 1816.4817, Significance = .00000

Table 6. Factor Loading of Concepts in Calculus — 1987/88

(Nos. of students: 483)

No. of Item	Factor I f_1	Factor II f_2	Factor III f_3	Factor IV f_4	Factor V f_5	Communality $h^2 = \Sigma f_i^2$
1	.03056	.44511	-.24831	.39680	-.32399	.52314
2	.21309	.06594	-.04220	.08137	.73873	.60388
3	.38333	.25979	.19686	.29491	-.32992	.44901
4	.49921	-.06826	.08354	.45057	.05684	.46710
5	.63254	.01456	.14587	.05354	.02299	.42500
6	.08515	-.00124	.10460	.70147	.07501	.51588
7	.28521	.57804	.20204	-.08616	-.05284	.46652
8	.63136	.23279	.02234	.10315	.18639	.49868
9	.53940	.03302	.14557	.09700	.00594	.32268
10	.30904	.17156	.23443	.48195	.05582	.41528
11	.11094	.43031	.51312	-.02037	-.00600	.46122
12	.13832	.65347	.12440	.32084	.00378	.56459
13	.05806	.67741	.16557	.02936	.24964	.55286
14	.52865	.15180	-.03839	.27614	.05550	.38332
15	.03210	.15174	.14881	.46699	.51483	.52933
16	.36227	.11982	.37244	.46079	.07066	.50163
17	.07687	.06890	.71247	.04730	.10272	.53106
18	.10000	.07212	.71778	.25794	-.06348	.60097
19	.26592	.23626	.44507	.14339	-.05029	.34771
20	.58074	.35650	.15392	-.04935	.06391	.49456
					Total	9.65442

Table 7. Multiple Regression of Fundamental School Mathematics — 1987/88

(Nos. of students: 543)

Dependent Variable	Related Item	Multiple r	r^2	Beta
F20 Area of parabolic region	F19 Tangent point of parabola	.48879	.23891	.23437
F = 55.29535	F03 Roots and horizontal tangent	.56095	.31466	.17683
Sig F = 0.0	F18 Tangent line of parabola	.59602	.35524	.21947
	F17 Free fall	.60886	.37071	.10656
	F01 Average rate of change of curve	.61433	.37740	.08208
	F04 Intersections of curve and line	.61833	.38233	.07836
F19 Tangent point of parabola	F18 Tangent line of parabola	.52515	.22579	.38129
F = 53.89780	F05 Length of tangent line	.56980	.32467	.13330
Sig F = 0.0	F14 Deformation of polynomials	.58806	.34582	.12872
	F01 Average rate of change of curve	.59970	.35964	.08887
	F02 Equation of line for give angle	.60758	.36915	.09868
	F12 Trigonometric equation	.61343	.37630	.09728
F18 Tangent line of parabola	F03 Roots and horizontal tangent lines	.42385	.17965	.26109
F = 36.17497	F12 Trigonometric equation	.46191	.21336	.13371
Sig F = 0.0	F04 Intersections of curve and line	.47860	.22905	.12598
	F02 Equation of line for given angle	.49331	.24336	.11533
	F16 Inequality of absolute values	.50195	.25196	.09886

(PIN = .050)

*F denotes item in Fundamental School Mathematics.

Table 8. Multiple Regression of Concepts of Calculus and Fundamental Mathematics — 1987/88

(Nos. of students: 351)

Dependent Variable	Related Item	Multiple r	r^2	Beta
C20 Graph of integral	C08 Graph of derivative	.35126	.12339	.20631
F = 18.35191	C07 Derivative of piecewise defined function	.43190	.18654	.16399
Sig F = 0.0	F08 Magnification of polygonal line	.46598	.21713	.18451
	C11 Application of differential	.48749	.23765	.15841
	C05 Rate of change of parabola	.50291	.25292	.12519
	F20 Area of parabolic region	.51333	.26351	.14239
	F17 Free fall	.52199	.27248	-.10578
C19 Fundamental theorem of calculus	C18 Application of integral	.23097	.05335	.14753
	C16 Definition of integral	.28759	.08271	.14884
F = 11.83877	C07 Derivative of piecewise defined function	.32677	.10678	.14706
Sig F = 0.0	C10 Cubic curve	.34697	.12039	.12102
C18 Application of integral	C17 Calculation of integral	.35287	.12452	.23871
F = 18.43581	C11 Application of differential	.41849	.17514	.22403
Sig F = 0.0	C16 Definition of integral	.44495	.19798	.14169
	C19 Fundamental theorem of calculus	.46203	.21347	.11720
	C08 Graph of derivative	.47496	.22559	-.14906
	F20 Area of parabolic region	.49327	.24332	.14094
C16 Definition of integral	F15 Synthetic division	.24332	.05921	.19705
F = 13.64394	C03 Continuity of function	.32223	.10383	.15144
Sig F = 0.0	C15 Area of trapezoid	.36402	.13251	.14106
	C05 Rate of change of parabola	.38939	.15162	.12931
	C10 Cubic curve	.40632	.16509	.12049

*F denotes item in Fundamental School Mathematics.
C denotes item in Calculus of Collegiate Mathematics.

(PIN = .050)

Table 8. Multiple Regression of Concepts of Calculus and Fundamental Mathematics — 1987/88
(Continued)

(Nos. of students: 351)

Dependent Variable	Related Item	Multiple r	r^2	Beta
C13 Proof of limit	C12 Proof of continuity	.41122	.16910	.32484
F = 22.19036	C07 Derivative of piecewise defined function	.43933	.19301	.11745
Sig F = 0.0	C02 Limits of number sequence	.46276	.21414	.15153
	C11 Application of differential	.48166	.23200	.14164
	F11 Graph of absolute function	.49330	.24334	.10885
C08 Graph of derivative	F03 Roots and horizontal tangent lines	.29873	.08924	.12960
F = 22.19036	F01 Average rate of change of curve	.36811	.13550	.13881
Sig F = 0.0	F08 Magnification of polygonal line	.40855	.16691	.18996
	C02 Limits of number sequence	.43386	.18823	.13825
	C05 Rate of change of parabola	.45370	.20584	.12645
	F17 Free fall	.46414	.21543	.11138
C07 Derivative of piecewise	F02 Equation of line for given angle	.27670	.07656	.12781
defined function	F18 Tangent line of parabola	.34571	.11951	.14164
F = 18.34480	C03 Continuity of function	.38970	.15187	.19379
Sig F = 0.0	F06 Reflection of polygonal lines	.43280	.18732	.18023
	F01 Average rate of change of curve	.45829	.21003	.15822

(PIN = .050)

*F denotes item in Fundamental School Mathematics.
C denotes item in Calculus of collegiate Mathematics.

Table 9.

Crosstabulation: Test I

F1
By F2

F1	F2 →	Count Col Pct	0 * Incorrect	1 * Correct	Row Total
		0 *	42	20	62
		Incorrect	25.9	10.6	17.7
		1 *	120	169	289
		Correct	74.1	89.4	82.3
		Column	162	189	351
		Total	46.2	53.8	100.0

Crosstabulation: Test II

C1
By C2

C1	C2 →	Count Col Pct	0 * Incorrect	1 * Correct	Row Total
		0 *	20	195	215
		Incorrect	66.7	60.7	61.3
		1 *	10	126	136
		Correct	33.3	39.3	38.7
		Column	30	321	351
		Total	8.5	91.5	100.0

*Scores 0,1,2 considered as incorrect.
Scores 3,4 as correct.

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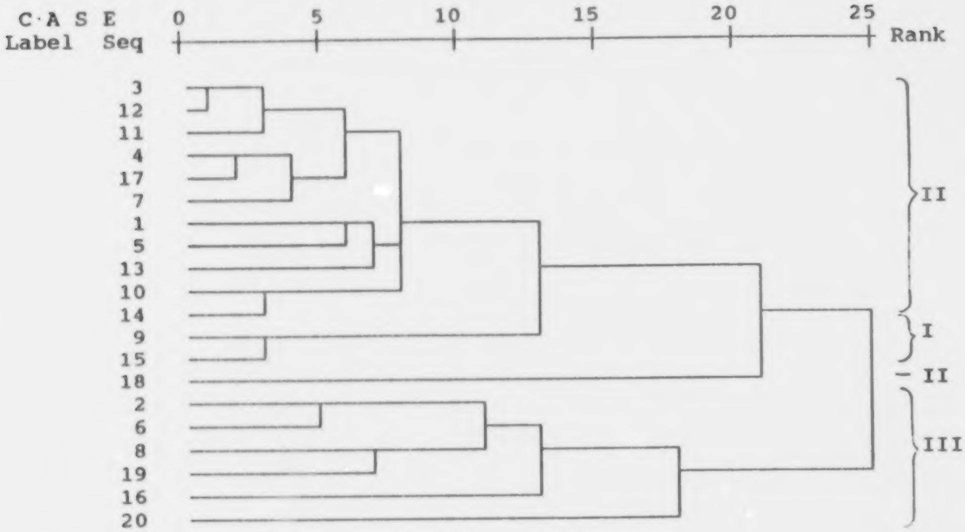
Table 10. Dendrograms of Cluster Analysis

Test I Rescaled Distance Cluster Combine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Test II Rescaled Distance Cluster Combine

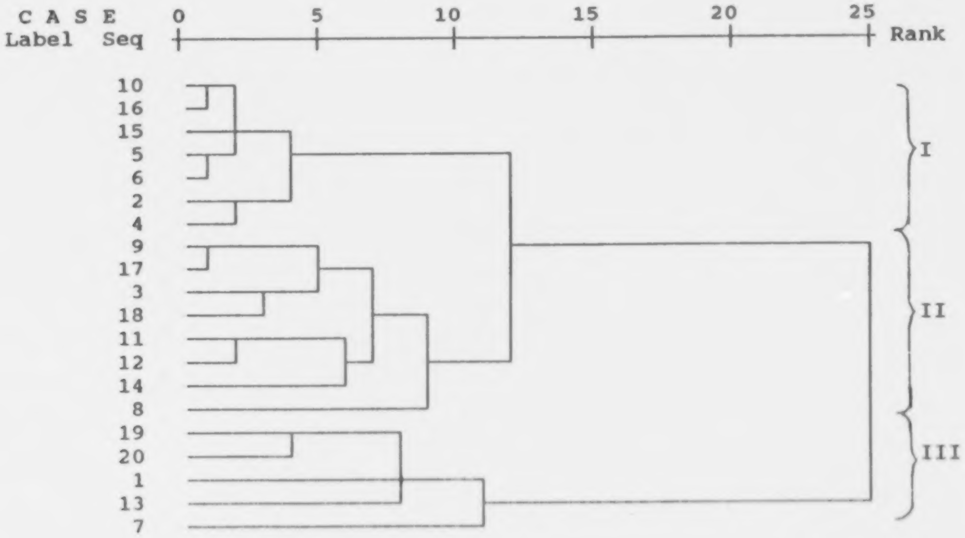
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Table 11. Measures of Conceptual Development of Fundamental School Mathematics 1987/88

(Nos. of students: 543)

No.	Item	Measure of Conceptual * Development	Rank of Difficulty **
F01	Average rate of change of curve	9	II
F02	Equation of line for given angle	14	III
F03	Roots and horizontal tangent lines	9	II
F04	Intersections of curve and line	9	II
F05	Length of tangent lines	10	II
F06	Reflection of polygonal lines	13	III
F07	Reflection and trnaslation of curves	9	II
F08	Magnification of polygonal line	15	III
F09	Partial fractions	8	I
F10	Addition formula of sine	9	II
F11	Graph of absolute value function	10	II
F12	Trigonometric equation	10	II
F13	Division of polynomials	11	II
F14	Deformation of polynomials	11	II
F15	Synthetic division	7	I
F16	Inequality of absolute values	12	III
F17	Free fall	9	II
F18	Tangent line of parabola	11	II
F19	Tangent point of parabola	15	III
F20	Area of parabolic region	14	III

*Measure of conceptual development assigned to items range from 6 to 15 points.
**Rank I, II and III indicate items of less, mid and most difficulty respectively.

Table 12. Measures of Conceptual Development of Calculus — 1987/88

(Nos. of students: 483)

No.	Item	Measure of Conceptual * Development	Rank of Difficulty **
C01	Sequence of polygonal lines	13	III
C02	Limits of number sequences	6	I
C03	Continuity of function	11	II
C04	Rate of change of line	6	I
C05	Rate of change of parabola	8	I
C06	Differentiation by definition	7	I
C07	Derivative of piecewise defined function	14	III
C08	Graph of derivative	11	II
C09	Motion of projectile	9	II
C10	Cubic curve	7	I
C11	Application of differential	11	II
C12	Proof of continuity	11	II
C13	Proof of limit	15	III
C14	Area of circle	10	II
C15	Area of trapezoid	7	I
C16	Definition of integral	8	I
C17	Calculation of integral	10	II
C18	Application of integral	11	II
C19	Fundamental theorem of calculus	14	III
C20	Graph of integral	14	III

*Measure of conceptual development assigned to items range from 6 to 15 points.

**Rank I, II and III indicate items of less, mid and most difficulty respectively.

Table 13.

t-test for: F1 (1987/88 with 1986/87)

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	351	3.1994	1.093	.058
Group 2	228	3.0307	1.240	.082

		Pooled Variance Estimate			Separate Variance Estiamte		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1.29	.035	1.72	577	.086	1.68	441.17	.095

t-test for: F2 (1987/88 with 1986/87)

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	351	2.5157	1.695	.090
Group 2	228	2.8114	1.640	.109

		Pooled Variance Estimate			Separate Variance Estiamte		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1.07	.594	-2.08	577	.038	-2.09	496.25	.037

t-test for: C1 (1987/88 with 1986/87)

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	351	1.5556	1.950	.104
Group 2	228	1.7456	1.911	.127

		Pooled Variance Estimate			Separate Variance Estiamte		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1.04	.747	-1.15	577	.249	-1.16	491.87	.247

t-test for: C2 (1987/88 with 1986/87)

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	351	3.8120	.641	.034
Group 2	228	3.4298	1.176	.078

		Pooled Variance Estimate			Separate Variance Estiamte		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
3.37	.000	5.05	577	.000	4.49	315.33	.000

Table 14-1. Correlation of Test Scores with Scores of Exams of Calculus Course 1986/1987

Correlation	1st Semester		2nd Semester	
	Mid-term Exam	Final Exam	Mid-term Exam	Final Exam
Test 1	.4608**	.3769*	.5131**	.4339**
Test 2	.4736**	.3003*	.3279*	.4854**
Test 3	.6552**	.3150*	.4755*	.5131**

N of Cases 65 (1 ~ 5 Outliers excluded)
1-tailed Significance: *.01 **.001

Table 14-2. Correlation of Test Scores with Scores of Exams of Calculus Course 1987/1988

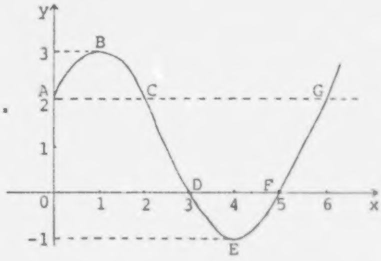
Correlation	1st Semester		2nd Semester	
	Mid-term Exam	Final Exam	Mid-term Exam	Final Exam
Test 1	.5179**	.5241**	.3707*	.4894**
Test 2	.5213**	.5994**	.4572**	.3603*

N of Cases 47 (1 ~ 5 Outliers excluded)
1-tailed Significance: *.01 **.001

Appendix 1

Test 1: Test on Fundamental Mathematics (Second revision)

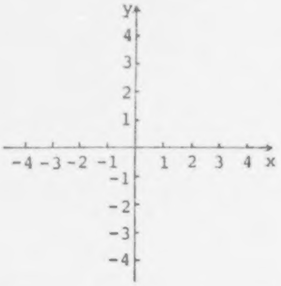
1. What is the average rate of change of y with respect to x,
   (1) from A to B?
   (2) from B to E?
   (3) from C to G?



2. Find equation of line,
   (1) that intersects y = x at the origin, with an angle of 15°.
   (2) that intersects y = x at the point (1,0), with an angle of 15°.

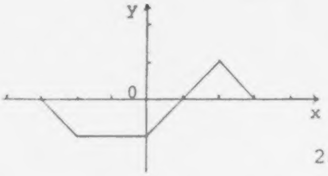
3. (1) Find the real roots of $x^3 - 3x + 2 = 0$.
   (2) Find the horizontal tangent lines of the curve $y = x^3 - 3x + 2$.

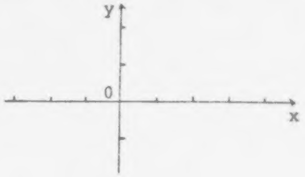
4. Sketch the curve $y = x^3$ and the line $y = 3x - 2$.
   Find the coordinates of the intersections.



5. (1) Find the length of tangent line from the point (5,0) to the circle $x^2 + y^2 = 9$.
   (2) Find the length of tangent line from the point (4,4) to the circle $x^2 + y^2 = 9$.

6. Given graph as below, sketch the graph of $g(x)$ ⅝ $-f(-|x|)$ in the right.





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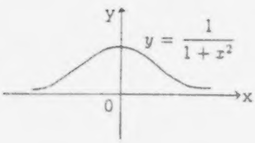
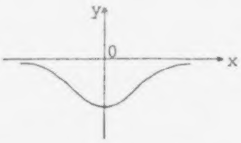
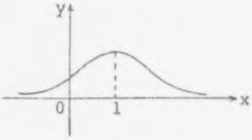
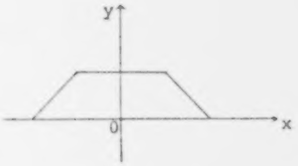
7. The graph of $y = \frac{1}{1+x^2}$ is as below, write the equation of the following curves.
   (1) y = ______________, (2) y = ______________.

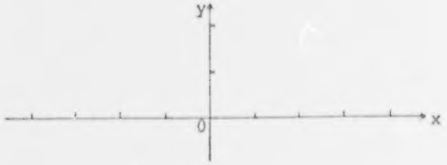






8. The graph of $y = f(x)$ is as below, sketch on the right, the graph of (1) $y = 2f(x)$. (2) $y = f(2x)$.



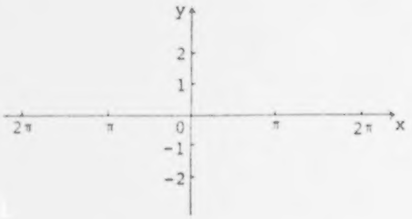


9. Let $\frac{1}{x^3-1} = \frac{A}{x-1} + \frac{Bx+C}{x^2+x+1}$. Find A = __________. B = ____________, C = __________.

10. If $\frac{\sqrt{3}}{2}\sin\theta + \frac{1}{2}\cos\theta = \sin(\theta+\alpha)$, find α = .

11. Sketch the graph of (1) $y = |x+1| + |x-1|$. (2) $y = |x+1| - |x-1|$.

12. Sketch the curve $y = \sin x$ and the line $y = \frac{x}{3}$; look at the figure and tell how many roots of $\sin x = \frac{x}{3}$ in $[-7, 5]$ there are.



13. Let $f(x) = 3(x+1)^3 - 2(x+1)^2 + 4(x+1) - 1$
(1) Find the remainder r(x) of f(x) divided by $(x+1)$.
(2) Let $\frac{f(x)}{x+1} = q(x) + \frac{r(x)}{x+1}$. Find the remainder $r_1(x)$ of q(x) divided by $(x+1)$.

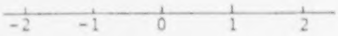
14. Let $f(x) = 3x^3 - x + 3$. If h(x) is a polynomial such that $h(x+1) = f(x)$, then the coefficient of the leading term of h(x) = ________, constant term = __________.

15. A synthetic division is carried out as below.

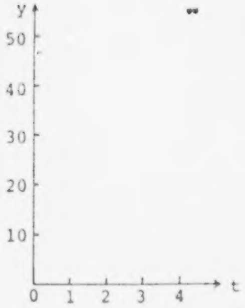
```
                1 + 0 + 0 - 1
              ______________________________
1 + 4 + 4  )  1 + 4 + 4 - 1 - 4 - 4
              1 + 4 + 4
              ______________________________
                        - 1 - 4 - 4
                        - 1 - 4 - 4
                        ____________________
                                  0
```

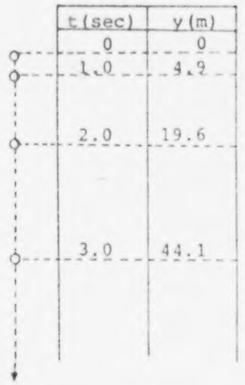
Where dividend = ____________,
divisor = ____________,
quotient = ____________,
remainder = ____________.

16. Find the solution set of the inequality $|x^2 - 2| < 1$ and represent it on the number line.



17. The data of the observation of a freely falling body is recorded in the right table.
    (1) Find average velocity when t varies from 2 to 3.
    (2) Use the data to plot the points for t = 0, 1, 2, 3, and then draw a smooth curve.





t (sec)	y (m)
0	0
1.0	4.9
2.0	19.6
3.0	44.1

18. Find the equation of the line tangent to $y = x^2$ and passing through the point P(2,4).

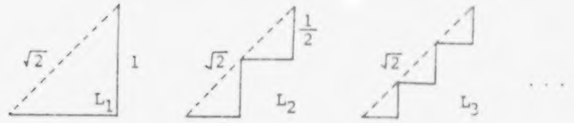
19. If a line passes through the point Q(0,−1) and is tangent to the curve $y = x^2$, find the tangent point.

20. Find the area of the region bounded by $y = x^2$ and $y = x$.

Appendix 2

Test 2: Test on Concepts in Calculus (Second revision)

1.



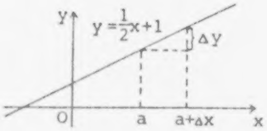
Consider the sequence of polygonal lines $L_1, L_2, L_3, \ldots, L_n, \ldots$.
Let a_n denoted the length of L_n, then $\lim_{n\to\infty} a_n =$ __________ .

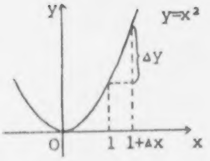
2. Find limit:
   (1) $\lim_{n\to\infty} (\frac{1}{2})^n =$. (2) $\lim_{n\to\infty} 2^{1/n} =$.

3. Which of the following functions is continuous at x = 0?

$$(1)\quad f(x) = \begin{cases} \dfrac{x}{|x|} & x \neq 0 \\ 0 & x = 0 \end{cases} \qquad (2)\quad f(x) = \begin{cases} x\cos\dfrac{1}{x} & x \neq 0 \\ 0 & x = 0 \end{cases}$$

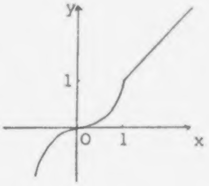
4. When $x = a$, $y =$ __________ .
   When $x = a + \Delta x$, increment of y, $\Delta y =$ __________ .
   average rate of change of y, $\dfrac{\Delta y}{\Delta x} =$ __________ .
   When x = a, the instantaneous rate of change of y, $\dfrac{dy}{dx} =$ __________ .





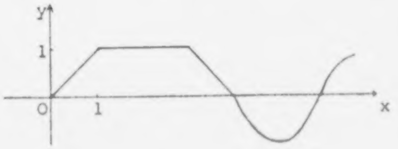
5. Let $y = x^2$. For $x = 1$, $\Delta x = 0.1$,
the average rate of change $\dfrac{\Delta y}{\Delta x}$ = __________.
For x = 1, the instantaneous rate of change of y,
with respect to x, $\dfrac{dy}{dx}$ = __________.

6. By definition $f'(x) = \lim_{x \to 0} \dfrac{f(x+\Delta x) - f(x)}{\Delta x}$, find the derivative of $f(x) = \dfrac{1}{x}$.
$f'(x)$ = __________.



7. Define $f(x) = \begin{cases} x^3 & x < 0 \\ x^2 & 0 \le x \le 1 \\ x & x > 1 \end{cases}$

find f′(0) and f′(1).



8. Observe the graph of y = f(x), then
sketch the graph of y = f′(x)
in the same coordinate plane.

9. A ball is thrown upward with an initial velocity of 19.6 m/sec.
The height at time t is $s(t) = 1.6 + 19.6t - 4.9t^2$.
Find (1) the velocity v(t) and the time t_0 at which the ball reaches the highest point.
(2) the average velocity $\bar{v}$ from t = 0 to t = 2.
(3) the time t_1, such that the velocity $v(t_1)$ equals to $\bar{v}$.

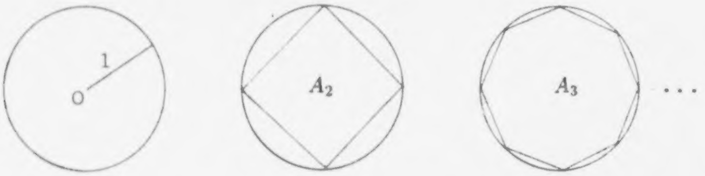
10. Find extrema and points of inflection of $y = x^3 - 3x$, and sketch the curve.

11. (1) Let $y = \sqrt{x}$, find the differential dy.
(2) Use differential dy to calculate approximation value of $\sqrt{99}$.

12. Use ϵ — δ method to prove the continuity of $f(x) = 2x - 3$ at $x = 2$.
(Hint: For given $\epsilon > 0$, find $\delta > 0$, such that if $|x - 2| < \delta$, then $|f(x) - f(2)| < \epsilon$)

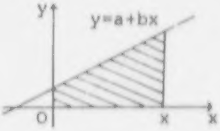
13. Definition of the limit $\lim_{x \to a} f(x) = b$: For given $\epsilon > 0$, there exists $\delta > 0$ such that when $0 < |x - a| < \delta$, then $|f(x) - b| < \epsilon$ holds. Can you use this definition to prove $\lim_{x \to 2} x^2 = 4$?

14. Construct inscribed regular polygons in a unit circle.



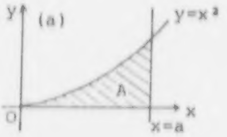
Let A_2 denote the area of the inscribed regular 2^2 -gon, A_3 denote the area of the inscribed regular 2^3 -gon, ..., and A_n denote area of the inscribed regular 2^n -gon. What is the limit of A_n, if $n \to \infty$? Explain.

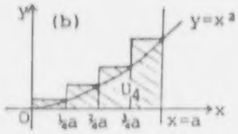
15. Find the area of the region shown in the figure: A = ____________.



16. The region bounded by $y = x^2$ x-axis and $x = a$ is shown in Fig. (a)
If $[0,a]$ is divided into 4 equal subintervals shown in Fig. (b), then the upper sum
$U_4 = \frac{a}{4}[\,(\frac{a}{4})^2 + (\frac{2a}{4})^2 + (\frac{3a}{4})^2 + (\frac{4a}{4})^2\,]$

(1) If the interval [0,a] is divided into n subintervals of equal length, then the upper sum U_n = ____________.
(2) Sum up the upper sum U_n.
(3) Find the limit of U_n and represent it by integral form.





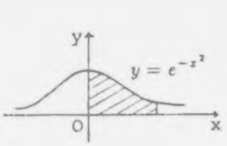
17. Evaluate the integrals: (1) $\int_0^{\infty} \frac{dx}{1+x^2}$ (2) $\int_0^1 \frac{dx}{2x+1}$

18. (1) Represent the arc length of the curve $y = \frac{2}{3}x^{\frac{3}{2}}$.
from $x = 0$ to $x = 3$ by integral, s = ____________.

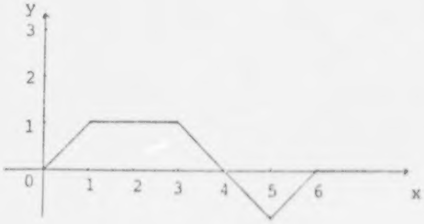
(2) The region bounded by $y = \frac{2}{3}x^{\frac{3}{2}}$, $y = 0$, $x = 0$ and $x = 3$, is revolved about the x-axis. Use integral to express the volume V of the resulting body, V = ____________.

19. (1) Let $F(x)$ denote the area of the region between $y = e^{-x^2}$ and x axis, from 0 to x, then $F'(x)$ = __________.

(2) If $F(x) = \int_0^{x^2+1} (u^3+1)^{1/2}du$, then $F'(x)$ = ____________.



20. Observe the graph of $y = f(x)$, then sketch the graph of
$y = F(x) = \int_0^x f(t)dt$
in the same coordinate plane.



微積分概念發展之研究

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摘　要

本文分析微積分基本概念，設計測驗問題，測試大學一年級學生對微積分的了解程度，並參照A. Orton所作"微積分了解之研究"進行統計分析。由此獲得學生對微積分了解的資料，建立微積分概念發展的構造。

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Students' Conceptual Developments on Shadow Formation and Their Relations to Formal and Concrete Operation Stages

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ABSTRACT

In this study, diagnostic group tests for investigating students' conceptions of shadow formation were designed based on Piaget's original clinical procedures. More than four hundred students, including high school students, non-science and science major college students, were tested using these instruments.

Various misconceptions as pointed out by previous investigators were confirmed and new features were also discovered among our subjects. The insight, meaning and developments of these conceptions were studied statistically and analysed from a Piagetian view of operational thinking. Three developmental levels of these conceptions were found.

The correlations of these conceptual levels and the general cognitive developmental stages, as indicated by the abilities in weight and volume concepts, were also statistically investigated. The levels of shadow formation were found to be highly dependent on these cognitive stages.

The meaning of these findings to teaching and learning were also discussed.

Key words: light concept, conception, shadow, cognition

I. Introduction

We begin to teach our children the reason for shadow formation when they are still in elementary school, and few of our elementary or high school teachers consider this a difficult subject to teach. However, many researchers, using various diagnostic methods, have found that the actual situation is very different from what we have expected. Most elementary and high school students cannot understand the theory of shadow formation of geometrical optics. Instead, they use an "emanating" model to explain the shadow phenomena (Piaget, 1960; Feher & Rice, 1986, 1988). The situation is of course interesting from the point of view of learning and teaching theory — what hinders our students from understanding such a common phenomenon and, to us, simple theory?

Piaget's theory of cognitive development can guide our study. Firstly, there is the stage theory of cognitive development. According to this theory, each student's learning or comprehension is limited by his mental stage of maturation. Thus, one of the aims of this study is to analyse the dependencies of the various stages of shadow conceptions upon the stages of mental maturation. Therefore we would be able to know the limit of learning the theory of shadow formation for each student and, furthermore, the sequence of teaching the concepts to our students.

Secondly, there is the theory of operational thinking. Piaget said (Piaget, 1960):

> *"To know an object, to know an event, is not simply to look at it and make a mental copy or image of it. To know an object is to act*

on it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed. An operation is thus the essence of knowledge.".

To understand the shadow phenomenon the student must be able to imagine the directions of the propagation light rays. To predict the variations of the shadow formed due to the variations of the experimental settings the student must be able to imagine the variations of the directions of the propagation of light rays. It is clear that the shadow problem is an appropriate example to check this operational theory: what are the effects of these mental imagination abilities on the understanding of shadow formation, in particular, and their relationships to cognitive development, in general?

II. Methodology

Subjects

Six student groups were studied, ranging from junior high to college students and from non-science to science background students (Table 1).

Instruments

A. *For Shadow Conception*

Materials

1. For the administrator
   one light source (10 watt small electric bulb)
   one white screen (20 cm by 20 cm)
   one metal ring with stand (diameter 4 cm)
2. For each participating student
   one ruler
   answer sheets with instructions

Form A Problems

#A1: After demonstrating the shadow phenomenon on the screen with the metal ring and the light source, the administrator asked the students to give a written explanation as to how the shadow was formed on the screen.

#A2: asked the students to use a graphic method to explain how the shadow was formed on the screen.

#A3: asked the students to predict and graphically explain the possible variations of the shadow on the screen if the intensity of the light source was varied.

#A4: the administrator turned off the light

Table 1. Number and Background of Subjects Studied

Student Groups	Background	N females	N males	Total
JHIGH	Systematically selected from a pool of about 3000 students in an urban junior high school (grades 7, 8, 9)	38	47	85
VHIGH	Chemical engineering students from an urban technological vocational high school (grades 10, 11)	21	29	50
SCAF	11 sergeant training classes of the Chinese Air Force Electronics and Communication School. They were either selected from a nation-wide entrance examination system or by a recommendation procedure (grades 10, 11)	0	182	182
NSCI	Non-science background college students enrolled in the general science literacy classes of National Taiwan Normal University	47	18	65
SCI	Science background college students enrolled in the general science literacy classes of National Taiwan Normal University	3	21	24
CMNU	Chemistry major college students of National Taiwan Normal Univeristy enrolled in a mechanics course. Most of them were juniors, with one freshman and two sophomores. About one third of them came from overseas Chinese families and were known to have learning difficulties in most science courses.	9	22	31
Total		118	319	437

source, and demonstrated the various possible positions of the screen, and then asked the students to predict and graphically explain the possible variations of the shadow on the screen if the light were on.

#A5: the administrator demonstrated the various possible positions of the light source, and then asked the students to predict and graphically explain the possible variations of the shadow on the screen if the light were turned on.

#A6: asked the students to predict and graphically explain the possible variations of the shadow on the screen if the light source were moved very far away.

Form B Problems

#B1: after demonstrating the shadow phenomenon on the screen with the metal ring and the light source, the administrator asked the students to give a written explanation as to how the shadow was formed on the screen.

#B2: asked the students to use a graphic method to explain how the shadow was formed on the screen.

#B3: the administrator demonstrated the various possible positions of the light source, and then asked the students to predict and explain the possible variations of the shadow on the screen if the light were on.

#B4: the administrator demonstrated the various possible positions of the screen, and then asked the students to predict and explain the possible variations of the shadow on the screen if the light were on.

#B5: the administrator demonstrated the various possible positions of the metal ring, and then asked the students to predict and explain the possible variations of the shadow on the screen if the light were on.

In problems #B3, #B4, #B5 we did not specifically ask the students to give graphic explanations as we had required in problems #A3, #A4, #A5. Therefore, not all students used a graphic method to answer these problems. In this study, student groups SCAF, NSCI, SCI were given the form A test and student groups VHIGH, JHIGH, CMNU were given the form B test.

B. For Cognitive Development

Three demonstrative group tests based on Piaget's theory were used:

1. displacement of water by metal cylinders (Karplus, 1978; Piaget & Inhelder, 1974)
2. conservation of volume by modeling clay (Piaget & Inhelder, 1974)
3. conservation of weight by modeling clay (Piaget & Inhelder 1974)

Four stages of students' cognitive development were classified according to Piaget's theory (Table 2). Student groups SCAF,NSCI,SCI were tested with these methods, and the percentage of subjects that could not be classified was less than 5% (Table 3).

Table 2. Classifying Characteristics for Cognitive Stages

Cognitive stages	Characteristics
IIIB	•in the cylinder problem, understood that the displacement of water was caused by the volume or size of the cylinder; that two cylinders with different weight and same volume would displace equal amounts of water. •in the conservation of volume problem, understood that the displacement of water by the modeling clay was caused by the size or volume of the clay, and that the amount of displacement of water would be the same irrespective of the deformation of the clay. •in the conservation of weight problem, understood that the weight of the modeling clay would be the same irrespective of the deformation of the clay.
IIIA	•gave correct answers in all three tests, but with ambiguous explanations and with no clear distinctions among the concepts of volume, weight, and mass.
IIB	•showed incorrect volume concept in either the cylinder problem or the conservation of volume problem, but in the conservation of weight problem understood that the weight of the modeling clay would be the same irrespective of the deformation of the clay.
IIA	•gave incorrect answers and explanations in all three tests.

Table 3. Cognitive Development Stages of Part of the Subjects*

Student Groups	Stages			
	IIA	IIB	IIIA	IIIB
SCAF (N = 174)	14.4	44.8	24.1	16.7
NSCI (N = 69)	0.0	29.0	4.3	66.7
SCI (N = 23)	0.0	8.7	4.3	87.0

*There were 5 unclassifiable responses.

III. Results

The Conceptual Models

Table 4 lists the students' descriptive models for shadow formation that we obtained from their answers to problem #A1 (we could do the same analysis for #B1). The BP model is the one that is most consistent with the orthodox theory of geometrical optics. The basic concepts are the straight movement of light rays and the absence of irradiation on the screen due to the blocking effect of the object. The SE model is characteristic of the 'emanating models' as discussed by Piaget among children of average ages 6-9 years (Piaget, 1960). These SE model students somehow think that the shadow is a kind of image of the object, created at the location of the object and emanating from the object when subjected to light irradiation. The S model conception is characteristic of a simple cause and effect reasoning. These students gave no explanation of the interacting mechanisms between light and object that cause the shadow phenomenon. The SE and S models are the main misconceptions for student groups SCAF and NSCI, and even a few students with science background are of this model too. Although many responses were unclassifiable, this classifiation scheme does provide us with a good understanding of these students' conceptions.

By analysing students' graphic answers to problems #A2 and #B2 we obtained a set of graphic models for shadow formation of finite distance settings (Fig. 1). As we can see these graphic models are parallel to those of the descriptive models. The SG model is the one that is consistent with the concept of geometrical optics. These students drew straight light rays starting from the source point, passing by the outer edges of the ring and projecting straight onto the screen, and the shadow was considered to be the dark area on the screen that light could not reach. On the other hand, the SE model students always drew the formation process in two steps: light rays first travel from the source to the object, and then from the object to the screen. The two-step process is demonstrated by the discontinuity of light rays at the position of the ring, and there are no definite geometrical relations between light rays and shadow sizes. The S model students gave no definite mechanisms for shadow formation. They only indicated a concern with the initial course of light irradiation and the final effect of shadow formation, and ignored the intermediate interaction processes between light and object. Students belonging to this model drew arbitrary straight rays to indicate the

Table 4. Descriptive Models and Their Percentage Distributions (#A1)

	Descriptive Models	Student Groups		
		SCAF	NSCI	SCI
BP:	*Light to the screen was blocked partially by the object, therefore some parts of the screen did not have any light reaching them, and the shadow was the dark area on the screen.	13.2	56.9	75.0
SE:	*An image was formed near the object when light irradiated the objects; the image then was projected onto the screen and formed the shadow *A dark image was formed behind the object when light irradiated the front area of the object, the image then was projected onto the screen and formed the shadow *The object blocked part of the light and therefore formed a dark shadow behind it, but the rest of the light kept traveling forward and therefore carried the image onto the screen.	51.6	18.5	4.2
S:	*Shadow was formed when light irradiated the object.	8.2	10.8	4.2
X:	*(unclassifiable responses)	27.0	13.8	16.6

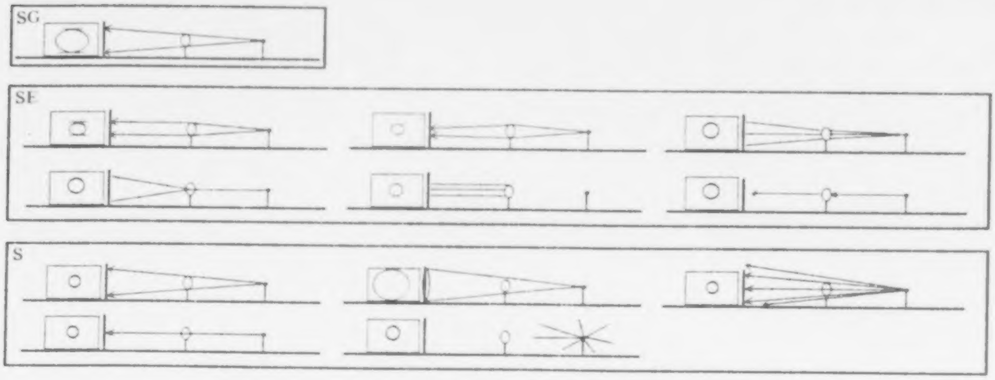

Fig. 1. Graphic models of finite distance setting (#A2, #B2)

Table 5. Distribution (%) of Graphic Models of Finite Distance Settings (#A2, #B2)

Graphic Models	#A2			#B2		
	Student Groups			Student Groups		
	SCAF	NSCI	SCI	VHIGH	JHIGH	CMNU
SG	21.4	76.9	91.7	64.0	40.0	87.1
SE	26.4	9.2	0.0	18.0	23.5	3.2
S	47.8	13.8	8.3	14.0	29.4	6.5
X	4.4	0.1	0.0	4.0	7.1	3.2

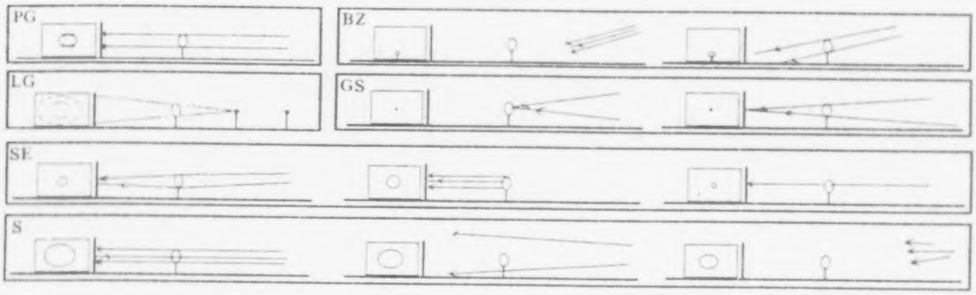

Fig. 2. Graphic models of infinite distance setting (#A6)

irradiation processes and a shadow with arbitrary size somewhere on the screen. Table 5 lists the distribution of these graphic models among the students tested. We can see that the non-geometrical models (SE and S) are the main conception models for the junior high school students (JHIGH) and military students (SCAF), and that even a few college science students (SCI and CMNU) also demonstrate these models.

Answers to problem #A6 provided the graphic models for the infinite settings, i.e. when the light source receded from the blocking object to infinity. The various models are duplicated as shown in Fig. 2, and their frequency distributions are listed in Table 6. We can see that the characteristics of models SE and S models are parallel to those of the finite distance problems. They are characterized either

Table 6. Distribution (%) of Graphic Models of Infinite Distance Settings (#A6)

	Graphic Models						
Student groups	BZ	GS	LG	PG	S	SE	X
SCAF	2.2	8.8	3.8	2.7	25.3	15.4	41.8
NSCI	0.0	3.1	4.6	50.8	3.1	0.0	38.5
SCI	0.0	4.2	0.0	79.2	0.0	0.0	16.7

by a two step process or by direct arbitrary irradiation on the object and screen, and that the shadow size has no definite relation to the light rays. The PG model indicates an ability of limiting reasoning process as the source recedes to infinity. Students of this model, based on the SG model of finite source distance, argued that the light rays passing by the outer edges of the ring would become parallel gradually as the source receded. They drew straight parallel light rays passing by the outer edges of the ring and projecting straight onto the screen.

On the other hand, the LG model is characterized by a deficiency of this limiting reasoning ability. Although their knowledge base was also the SG model of finite distances, they used a strategy of trial and error to find out that the shadow should become smaller as the source distance was increased, and they failed to conclude that eventually the size of the shadow would approach that of the object as the source distance increased more and more.

The BZ and GS graphic models reveal the students' conceptions of the finite propagation power of light. The conceptions of BZ model users are more or less mechanical in nature, in that these students believe that light possesses some kind of finite momentum energy, which would be gradually used up as it propagates through space, and would fall to the ground like a projectile. The GS students demonstrate a convergent type of finite light propagation. They believe that the outer part of a light beam would dissipate away from the beam as it travels through space, and the cross section of the beam would become smaller and smaller. These models of light propagation are of course completely different from the divergent conception of geometrical optics, in which we think that the total flux of light is conserved and can travel to infinity, only that the energy intensity decreases according to the inverse square law.

Variational Properties of the Conceptual Models

Students' predictions of shadow properties with respect to the variations of the experimental setups reveal more characteristics of their shadow conceptions. As we shall see, students' difficulties can be ascribed to three origins: the emanating model of shadow formation; the finite propagation power of light; the ability of operational thinking about light rays.

Table 7 lists the kinds of conceptions with respect to the variations of light intensity. Students belonging to the SX type of prediction believed that the variation of light intensity would affect the size of the black image emanated from the object (metal ring). All these students believed that stronger light would

Table 7. Predictions on Shadow Properties When Light Intensity Varies (#A3)

		Frequencies (%)		
Types of Prediction		SCAF	NSCI	SCI
**SF :	shadow contour would diffuse and become fuzzy from less intensive source	8.8	1.5	4.2
*SI :	shadow size is independent of source intensity	65.4	49.2	66.7
*SV :	brighter background with more intensive light, thus better visibility for the shadow	3.3	41.5	29.2
**SWX :	darker shadow from less intensive source	2.2	1.5	0.0
**SX :	size would be different for different source intensity	18.1	4.6	0.0
X :	(unclassifiable responses)	2.2	1.5	0.0

*geometrical predictions; **non-geometrical predictions

Table 8. Predictions of Shadow Properties when the Screen Position Varies (#A4 & #B4)

		Frequencies (%)					
		#A4			#B4		
	Types of prediction	SCAF	NSCI	SCI	VHIGH	JHIGH	CMNU
**II :	shadow will be the same size for either closer or farther screen	7.7	0.0	0.0	18.0	20.0	9.7
**LI :	larger for closer screen; same size for farther screen	0.0	0.0	0.0	0.0	3.5	0.0
**LL:	larger for either closer or farther screen	0.0	0.0	0.0	0.0	1.2	0.0
**LS:	larger for closer screen; smaller for farther screen	20.3	3.1	0.0	24.0	15.3	16.1
**SI :	smaller for closer screen; same size for farther screen	0.0	0.0	0.0	0.0	0.0	0.0
*SL :	smaller for closer screen; larger for farther screen	67.0	96.9	100.0	58.0	58.8	58.1
**Z :	shadow will move to the lower part of the screen for greater screen distance	2.2	0.0	0.0	0.0	0.0	0.0
X :	(unclassifiable responses)	2.7	0.0	0.0	0.0	1.2	16.1

*geometrical predictions; **non-geometrical predictions

make bigger shadows and weaker light would make smaller shadows and no student predicted the opposite situation. On the other hand, the SWX students believed that the light intensity would affect the darkness of the emanated image: "darker" light would produce a darker image. Similarly, the SF students believed that a fainter light would produce a fuzzier image.

In Table 8, the II and LS are the dominating types of non-geometrical prediction for the case of screen position variations. The II students believed that the distance from the object to the screen would not affect the size of the shadow. The LS students believed that the size of the emanated image would shrink as it travelled through space, and therefore produce larger shadows for closer screens and smaller shadows for farther screens.

In Table 9, the SL type of prediction stands for the main misconception for the case of variation of source position. These students believed that a source closer to the object would make a smaller shadow and a source farther would make a larger shadow. Somehow these students thought that a farther source would give a more divergent light and therefore more dispersing power to liberate a larger image from the object.

Students' responses to problem #B5 (Table 10) are rather complicated. Their reactions depended on their focusing point at the moment of solving the problem (the variation in the distance between the object and screen, or the variation in the distance between object and source), or on a regulated conception from these different points of view. The LL, SS types of predictions may be the results of these regulatory processes. Students making these types of predictions seemed to have adopted a kind of conception of the optimum, i.e. they took the present situation as a situation that was giving the largest or smallest shadow, and any variation of the present situation would always make the shadow smaller or bigger. We can see that this conception of the optimum also happened in the responses to #B4 (Table 8) and #B3 (Table 9). That these optimization processes only happened in the Form B problems but not in the Form A problems is quite intriguing. Certainly this must have something to do with the absence of drawing activities. In problems #B3, #B4, #B5 we did not require the students to give graphic explanations, while in problems #A3, #A4, #A5 we specifically required the students to give graphic explanations.

The underlying rationale of the students' predictions (Table 11) when the light source recedes to infinity, can be easily understood from a contingency table of the graphic models with the types of prediction (Table 12). We see that 18 out of the 19 GS model students gave the SP type predictions. That is, the GS students believed that a light beam from a far distant source would have a very small cross section and therefore could only produce a very small shadow. We also see that out of the four BZ graphic model students, two predicted that there would be no shadow on the screen and another two gave the SP.Z type prediction. In other words, the BZ students con-

Table 9. Predictions of Shadow Properties When the Source Position Varies (#A5 & #B3)

	Types of prediction	Frequencies (%)					
		#A5			#B3		
		SCAF	NSCI	SCI	VHIGH	JHIGH	CMNU
**II :	shadow will be the same size regardless of object-to screen distance	9.9	0.0	0.0	4.0	7.1	0.0
**IS :	same size for closer source; smaller for farther source	0.0	0.0	0.0	0.0	1.2	0.0
**LI :	larger for closer source; same size for farther source	0.0	0.0	0.0	0.0	1.2	0.0
**LL:	larger for either closer source or farther source	0.0	0.0	0.0	0.0	9.4	0.0
*LS :	larger for closer source; smaller for farther source	62.1	96.9	100.0	72.0	44.7	67.7
**SL:	smaller for closer source; larger for farther source	16.5	3.1	0.0	24.0	29.4	6.5
**SS:	smaller for either closer or farther source	0.0	0.0	0.0	0.0	5.9	6.5
**Z :	shadow will move lower on the screen for greater source distance	2.2	0.0	0.0	0.0	0.0	0.0
X :	(unclassifiable responses)	9.3	0.0	0.0	0.0	1.2	19.3

*geometrical predictions; **non-geometrical predictions

Table 10. Predictions of Shadow Properties When the Meter Ring Position Varies (#B5)

	Types of Prediction	Frequencies (%)		
		VHIGH	JHIGH	CMNU
**II :	shadow size would not change for different positions of the ring	6.0	11.8	0.0
**IS :	shadow size would not change when the ring moved toward the screen; would become smaller when the ring moved toward the source	2.0	0.0	0.0
**LL:	shadow would become larger when the ring was moved	0.0	4.7	0.0
**LS:	shadow would become larger when the ring was moved toward the screen and would become smaller when the ring was moved toward the source	18.0	12.9	6.5
*SL :	shadow would become smaller when the ring was moved toward the screen and would become larger when the ring was moved toward the source	72.0	57.6	67.7
**SS:	shadow would become smaller when the ring was moved	0.0	10.6	6.5
X :	(unclassifiable responses)	2.0	2.4	19.4

*geometrical predictions; **non-geometrical predictions

ceived that light beam from a far distant source would have used up its propagation power and fallen down to the ground, and therefore there would be either no shadow on the screen or a shadow on the bottom of the screen. All 10 LG students gave the SS type of prediction. This means that students who can use graphic methods to predict the shadow phenomenon are not necessarily able to conceive the transformation

Table 11. Predictions on Shadow Properties When the Light Soucer Recedes to Infinity (#A6)

Types of Prediction		Frequencies (%) SCAF	NSCI	SCI
**SS :	shadow will become smaller	7.7	7.7	0.0
**SF :	shadow contour will become diffuse and fuzzy	1.1	0.0	0.0
**SI :	shadow size will not change	1.6	0.0	0.0
**SL :	shadow will become larger	12.1	1.5	0.0
SN :	shadow will be invisible; shadow will not exist	43.4	24.6	8.3
*SO :	shadow will become the same size as the ring	2.2	55.4	83.3
**SP :	shadow will shrink to a point size	24.2	7.7	8.3
**SP.Z:	shadow will shrink to a point size and move to the lower part of the screen	3.3	0.0	0.0
X :	(unclassifiable responses)	4.4	3.1	0.0

*geometrical predictions; **non-geometrical predictions

Table 12. Contingency Table of Graphic Models with Transformation Concepts When Light Source Recedes to Infinity (#A6; SCAF, NSCI, SCI)

Types of Prediction	Graphic Models (#A6) BZ	GS	LG	PG	S	SE	X	Total Students
SS	0	0	10	0	2	2	5	19
SF	0	0	0	1	1	0	0	2
SI	0	0	0	0	0	1	2	3
SL	0	0	0	0	10	5	8	23
SN	2	1	0	2	21	9	62	97
SO	0	0	0	58	0	0	2	60
SP	0	18	0	0	10	8	15	51
SP.Z	2	0	0	0	1	0	3	6
X	0	0	0	0	3	3	4	10
Total Students	4	19	10	61	48	28	101	271

properties of light beams. Finally, we see that the non-geometrical predictions of S and SE graphic models are very common for this limiting case as in the cases of finite experimental settings.

Developmental Analyses

We have seen that most students, including some of the college science majors, have difficulties in understanding the shadow formation theory of geometrical optics. Our results are basically consistent with Piaget's interview findings for young children (Piaget, 1960; Inhelder & Piaget, 1958).

The performance of the students on the problems revealed the characteristics of the so-called ability for operational thinking (Piaget, 1964). In order to solve the problems, the subject must be able to think of the transformation of the light rays corresponding to the variations of the experimental settings, and that these mental operation abilities are supposedly dependent on the students' cognitive developmental stages as represented by the weight and volume conceptions (Piaget & Inhelder, 1974). The results of Tables 13, 14 and 15 indicate how these mental transformation abilities affect students' understanding for the shadow problems, while the results of Table 16 demonstrate the close relationship between these transformation abilities and the stages of cognitive development.

Firstly, we see from Table 13 that the two graphic conceptual levels, as demonstrated by the students in problems #A2 and #A6 respectively, reveal a very clear stage relation: all of the 57 PG students also belong to the SG conceptual level, but, on the other hand, among the 111 SG students, 54 did not reach the PG level. This simply means that to be able to think of the transformations or variations of the

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Table 13. Contingency Table of Graphic Models of #A2 with Graphic Models of #A6 (student groups: SCAF, NSCI, SCI)

Graphic Models of #A6	Graphic Models of #A2 SGN*	SG	Total Subjects
PG		57	57
PGN*	160	54	214
Total Subjects	160	111	271

**Chi-sq = 100.98, df = 1, $p < 0.001$

*SGN = non-geometrical graphic models belong to either S, SE or X in #A2.
PGN = non-geometrical graphic models belong to either BZ, GS, LG, S, SE or X in #A6.

light rays as the light source recedes to infinity requires a much higher mental ability than to draw correct light rays that describe the shadow phenomena of definite experimental settings.

From Table 14 and 15 we see more evidence for the effects of this mental operation. There is a clear difference between students' performance on Form A and Form B problems. The difference between the two sets of problems is that in problems #A3, #A4, and #A5 the students had been asked to give graphic explanations, while in problems #B3, #B4, #B5 the students had not been asked to give graphic explanations. Thus it is conceivable that students tended to use a graphic method to solve the problems #A3, #A4,

Table 14. Contingency Tables of Graphic Conceptual Levels with Variational Conceptual Levels for FORM A Problems (student groups: SCAF, NSCI, SCI)

Variational Levels by #A4 & #A5	Graphic Levels by #A2 & #A6 SGN	SG	PG	Total Subjects
TG*	67	51	57	175
TGN**	90	3		93

Chi-sq = 86.0, df = 2, $p < 0.001$

by #A3	Graphic Levels by #A2 & #A6			
IG*	113	45	49	207
IGN**	43	9	7	59

Chi-sq = 6.61, df = 2, $p < 0.05$

*TG = level consistent with geometrical optics for spatial variations of source and screen positions (#A4 & #A5); TGN = level inconsistent with geometrical optics

**IG = level consistent with geometrical optics for intensity variations (#A3); IGN = level inconsistent with geometrical optics

Table 15. Contingency Tables of Graphic Conceptual Levels with Variational Conceptual Levels for FORM B Problems (student groups: VHIEH, JHIGH, CMNU)

Variational Levels by #B3 & #B4	Graphic Levels by #B2 SGN	SG or PG	Total Subjects
TG*	19	44	63
TGN**	53	44	97

Chi-sq = 8.3, df = 1, $p < 0.005$

by #B5	Graphic Levels by #B2		
RG*	39	67	106
RGN**	33	19	52

Chi-sq = 8.6, df = 1, $p < 0.005$

*TG = level consistent with geometrical optics for spatial variations of source and screen positions (#B3 & #B4); TGN = level inconsistent with geometrical optics

**RG = level consistent with geometrical optics for spatial variations of metal ring position (#B5); RGN = level inconsistent with geometrical optics

Table 16. Contingency Table of Graphic Levels with Cognitive Developments (student groups; SCAF, NSCI, SCI)

Graphic Levels by #A2 & #A6	Cognitive Stages IIA	IIB	IIIA	IIIB	Total Subjects
PG		5	6	42	53
SG		22	8	19	49
SGN	25	73	32	34	164
Total Subjects	25	100	46	95	266

Chi-sq = 69.7, df = 6, p < 0.001

#A5, while, on the other hand, for problems #B3, #B4, #B5, students tended to imagine the possible transformations of the light beams for solving the problems. Comparing the performances for the problems of spatial variations of source and screen (levels TG & TGN) as related to different graphic levels in Tables 14, 15, we can see the influences of these different approaches to the problems. Among the 108 SG or PG graphic model students for the Form A problems, only 3 (2.8%) did not reach the TG variational level, but among the 88 SG or PG for the Form B problems, 44 (50%) could not reach the TG level. Thus, it is clear that the ability to draw diagrams and to think of the variations of the light rays are not identical. Drawing correct diagrams requires lower mental ability, while thinking of the variations of the light rays require higher mental ability.

The relationship between mental transformation abilities and cognitive developmental stages is displayed in Table 16, which shows that:

(1) No IIA stage students reached an SG or PG graphic level.
(2) Less than 15% of the IIB and IIIA stage students reached a PG graphic level, but about 44% of the IIIB stage students demonstrated a PG level.
(3) About 27% of the IIB students, and 44% of the IIIA students, and 64% of the IIIB students reached an SG or PG graphic level.

The above facts indicate that to achieve a fair understanding (SG level) of the shadow problem of geometrical optics, the student must be at least at the IIB cognitive stage. This level of understanding is characteristic of a static nature and needs a concrete method (e.g. graphic drawing) to help to make correct predictions on transformational problems. To have a good chance to achieve a high level understanding (PG level) of the shadow problem of geometrical optics, the student must be at a formal operational stage IIIB. This level of understanding is characteristic of the nature of operations.

The relation of the intensity variation levels IG and IGN to the graphic levels is also worth mentioning (Table 14). It is seen that the understanding that the shape of the shadow is independent of light intensity is closely related to a student's ability to mentally transform light rays. This fact supports Piaget's view that an operation is the essence of knowledge (Piaget, 1964).

IV. Implications

This study has proved again that the so-called spontaneous conceptions or misconceptions do play crucial roles in the effective learning of science. Our data has indicated that even college science and non-science students who have received many years of traditional optics education, may still retain misconceptions acquired during their very early years. Doubtlessly, any new effort to improve our science teaching must take these facts into account. Perhaps the first thing we should do is to let our teachers know about students' various misconceptions. Teachers equipped with such knowledge would be more sensitive to their students' underlying conceptions in the classrooms and thus might be able to redirect their teaching strategies if necessary. However, we do believe that careful research must be done before we can really understand the implications of these misconceptions upon the teaching and learning of science. It is clear that the traditional ways of telling the students the truth directly, or of showing the students the correct facts, is ineffective in teaching most scientific concepts. We must try to respect more of our students' natural conceptions, and try to start the teaching from these conceptions. And, it is only when we can induce a student to reconstruct his own conceptions, that we can say that the student has learned something. It seems that Piaget's theory of "self-regulation" is a good guide for this approach. Based on this theory, an effective curriculum should somehow be able to stimulate a kind of "cognitive conflict" among the individual student's conceptions. Only through these internal conflicts can the student be aware of the weaknesses of his own conceptions and be willing to modify and reconstruct his originally inappropriate conceptions.

It is also clear that the design of science curricula must take into account student cognitive development. Our current science curriculum is far from this basic requirement. The shadow concept is a standard example of poor curriculum design. We arranged our elementary school children (grade 2) to learn this concept of shadow, in spite of the fact that most of these students' developmental levels are in the early concrete operational stages. Students at these levels simply do not have the mental operational power to grasp the meanings of these physical phenomena.

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References

Anderson, B., & Karrqvist, C. (1983). How Swedish pupils,aged 12-15 years, understand light and its properties. *Eur. J. Sci.Educ.*, *5*(4), 387-402.

Anderson, C. W., & Smith, E. L. (1986). *Children's conceptions of light and colour: Understanding the role of unseen rays.* Research Series No. 166. Michigan State Univ., East Lansing, Institute for Research on Teaching.

Eaton, J. F., Anderson, C. W., and Smith, E. L. (1984). Students' misconceptions interfere with science learning: Case studies on fifth-grade students. *The Elementary School Journal. 84*(4), 365-379.

Feher, E., & Rice, K. (1986). Shadow shapes. *Science and Children*, 6-9.

Feher, E., & Rice, K. (1988). Shadows and anti-images: Children's conceptions of light and vision. *Sci. Edu., 72*(5), 637-649.

Inhelder, B., & Piaget, J.(1958). *The growth of logical thinking from childhood to adolescence.* Basic Books.

Karplus, R., Lawson, A. E., Wollman, W., Appel, M., Bernoff, R., Howe, A., Rusch, J. J., and Sullivan, F. (1978). *Science teaching and the development of reasoning (Physics).* Berkeley, California:University of California.

Piaget, J. (1960). *The child's conception of physical causality.* New Jersey: Littlefield, Adams & Co.

Piaget, J. (1964). Cognitive development in children: Development and learning. *Journal of Research in Science Teaching, 2,* 176-186.

Piaget, J., and Inhelder, B. (1974). *The child's construction of quantities.* New York: Basic Books, Inc.

Rosa, C. L., Mayer, M., Patrizi, P., and Vicentini-Missoni, M. (1984). Common sense knowledge in optics: Preliminary results of an investigation into the properties of light. *Eur. J. Sci. Ed, 6*(4), 387-397.

Smith, D. C. (1987). Primary teachers' misconceptions about light and shadows. In D. J. Novak (Ed.). *Proceedings of the second international seminar: Misconceptions and educational strategies in science and mathematics,* #2.Cornell University.

Stead, B. F., & Osborne, R. J. (1980). Exploring science students' concepts of light. *Austr. Sci.Teach. Jour., 26,* 84-90.

Watts, D. M. (1987). Student's conceptions of light: A case study. *Physics Education, 20,* 183-187.

學生投影概念的發展分析

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摘　要

本研究共設計了兩套作爲診斷學生投影概念的示範實驗群測工具。這些工具的設計參考了皮亞傑原始的個別面診過程。診斷對象約四百位學生，其中包括國中、高中及大學理科和非理科的學生。

本研究不祇是重新確認了前人研究報告所宣稱關於學生的若干自發性投影概念，同時也發現了許多新的概念特性。

根據皮亞傑關於思想的操作觀點，我們對這些投影概念的特性和發展，作了深一層的探討和統計分析。研究結果發現這些概念可以區分爲三個發展階層。

我們也分析了學生的投影概念階層和代表一般認知成長的重量和體積概念的關係。它們之間有顯著的相關性。

本研究並且嘗試探討了這些發現在教學上的意義。

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A Neural Network Approach to Design an Intelligent Computer Aided-Instruction System*

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ABSTRACT

A flexible and student-oriented intelligent computer-aided instruction system is proposed in this paper. The system employs a trainable neural network technique to infer the student's learning state. A prototype of the system is developed on an Apple Macintosh computer, and a college-level course is programmed to demonstrate the feasibility of the proposed approach. It becomes evident that the properties of individualization, easy comprehensiveness, natural encoding, and fault tolerance are all characteristics of the system.

Key words: intelligent computer-aided instruction, artificial neural network, authoring system

I. Introduction

The need for an adaptive, flexible, and individualized intelligent computer-aided instruction (ICAI) system motivated the exploration of this study. The design of such an instruction system has been the subject of much research. Usually, an ICAI system applies the techniques of traditional artificial intelligence and expert system (AI/ES) to facilitate the ICAI subsystems, such as the problem solver expertise, the grammar-based problem generator, and the rule-based tutoring system. Atkinson (1972) pointed out that an effective instruction system must be adaptive (McCombs and McDaniel, 1981; Park and Tennyson, 1983; Park, 1982; Tennyson and Christensen, 1984). Other techniques, such as the Baysian approach, have also been proposed to handle the dynamic properties of student's responses (Park and Tennyson, 1983). While all of the developed techniques are useful, none provides an adaptive, flexible, individualized, and intelligent system.

Previously-developed systems have used fixed teaching strategies. The student's learning process is completely controlled by the computer. This kind of approach is inflexible and is unable to become individualized with each student. On the other hand, a system without a fixed teaching strategy may be very individualized. Such a completely flexible strategy, however, will bring a student limited benefit when he (she) is unable to plan his (her) studies.

Therefore, an optimal ICAI system should exist somewhere between the inflexible and the completely flexible extremes. That is, the best system should allow the student to move at his own pace while providing a guided course of study unique to that student. This ideal method is achieved through the development of a system that loosely guides a student's course of study based on his learning state. The system is able to recognize the student's learning state and makes the appropriate suggestions. The student is then able to follow the suggestions or to ignore them.

Additionally, the system should infer the student's learning state through evaluation of his test scores. Traditional means of artificial intelligence handle this task poorly. As a result, the development of a trainable neural network is necessary.

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There are three basic shortcomings to AI/ES in regard to ICAI. First, AI/ES is not capable of working with an incomplete data set; for example, if a student's test is unfinished, AI/ES is unable to process the data, but a neural network is capable of handling the task.

Next, the processing speed of AI/ES is too slow to satisfactorily complete the task. However, a neural network is better suited to evaluate a student's test scores since its processing time is much improved over that of AI/ES.

Finally, a system employing AI/ES requires the use of a knowledge engineer. An AI/ES system uses a teacher's rules for predicting students' learning states. A knowledge engineer, in some cases a person and in others a computer, has to translate these rules for the computer. This translation process — from a teacher to a knowledge engineer; then, from a knowledge engineer to computer — creates problems in which the translation is usually imperfect. A neural network, on the other hand, does not suffer from these problems as no teacher's rules are translated to the computer.

A new neural network has been developed for the system described in this paper, and a college-level computer science course in data structure is used as the example courseware for the testing of the proposed system. Moreover, hypertext technique is used for making the courseware implementation and the utilization easier.

II. The Framework of CAINET

In this section, the concept of predicting the student's learning state is explained. Then, the framework of CAINET will be discussed.

From the system's point of view, the process of human intelligence can be illustrated by the block diagram of Fig. 1, in which the central black box provides the functions of knowledge representation and knowledge application. The functions contained within the black box are unknown. There are many ways to study this black box. One is defining and describing the components and their functions as clearly as possible. This is very difficult since these components and functions are unknown. In this instance, it may be better to concentrate only on the input and the output. With this concept in mind, the black box is described by the mapping operation of the input and output as shown in Fig. 2.

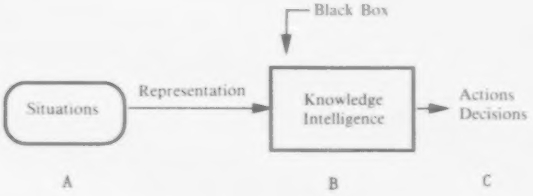


Fig. 1. The application of a human's intelligence

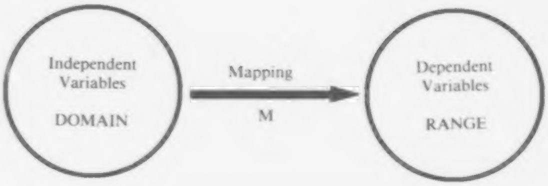


Fig. 2. The mathematical presentation of Fig. 1

The structure of mapping M in Fig. 2 may be arbitrary. Some kind of prior knowledge of M is necessarily required for its implementation. For example, M can be assumed to be a multiple linear regression model, a set of production rules, a Boolean function, etc. One of the difficulties is to decide the specifications of M because the output of the operation is dependent on those specifications. That is, if M is specified to be a linear regression model, the result of the system performance may be completely different from that obtained by a nonlinear model.

The other difficulty of human intelligence representation is the limitation of prior knowledge. If more prior knowledge is identified beforehand, the ambiguity of system specification will be greatly reduced. For example, during the design stage, the effectiveness of the rule-based expert system relies on successful communications between the knowledge engineers and the experts.

Moreover, some problems may occur when the available data are incomplete. Under this circumstance, there is a practical difficulty no matter what kind of method is chosen. That is to say, even if the mapping M is believed to be proper, M is unable to work correctly due to incomplete data. In addition, no matter whether the student's answer is correct or not, potential faults of the answer may occur. These include stochastic faults originating from students' guessing answers intuitively, from incomplete student answers due to unfinished exercises, etc.

Even if the student replies with a correct answer to the question, it is still not easy to determine whether the student really understands the concept hidden implicitly behind the question. On the other hand, it is difficult to test a single concept at one time because the proper judgement can not usually be determined without completion of the test. Within a flexible system, the tests are usually incomplete. Then, how can the inferential method be correctly verified based on a student's incomplete test? Owing to the complexity and difficulty in designing the proper tests, it seems that the traditional statistical and AI/ES techniques for inferring students' learning states must be extremely sophisticated in order to cope with the incomplete and faulty data. Subsequently, this increasing complexity increases the software developing cost.

Consequently, neural network approach may play a significant role in providing a new computation model that is completely different from most of the conventional models. A neural network contains a group of units rather than a single processing component. Hopfield Net (Carpenter, 1989), for example, and other associated memory neural net models are proposed for recovering the incomplete data of some researchers. Furthermore, the multilayer perceptron with the backpropagation learning rule is also used to approximate an arbitrary complex mapping of M (McClelland and Rumelhart, 1987a).

After reviewing the existing models of neural network approach, this paper proposes the design of a new neural network model, which is called "CAINET". CAINET is designed to infer the student's learning state in the example ICAI system (a college level computer science course in data structure).

The architecture of CAINET is illustrated in Fig. 3.

Fig. 3 consists of three layers: the input, the hidden, and the output. The framework of the CAINET subsystem can be represented as an 8-tuple:

$$\text{CAINET} = (P, A, F, C, T, R, L, E),$$

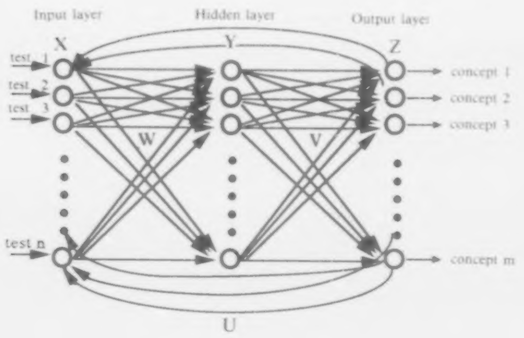


Fig. 3. Cainet

where

P is a set of processing units,

A is a set of states of activation,

F is an output function for each unit,

C is a set of patterns of connectivity among units,

T is a set of propagation rules for propagating patterns of activities through the CAINET of connectivities,

R is a set of activation rules for combining the inputs interfering on a unit with the current state of that unit to produce a new state of activation for the unit,

L is a learning rule by which patterns of connectivity are modified by experience, and

E is an environment within which the system can operate.

All of these components are described in the following paragraphs. The format is basically based on the framework of McClelland and Rumelhart's work (1987).

(1) P, a set of processing units

P = {TEST, CONCEPT},

where

TEST = {test 1, test 2, ..., test n}

CONCEPT = {concept 1, concept 2, ..., concept n}

That is, in CAINET, the set of processing units is decomposed into two subsets : TEST and CONCEPT. TEST contains scores of test results, and CONCEPT consists of a set of teaching concepts in CAINET. TEST then constitutes the input layer, and CONCEPT incorporates both the hidden and the output layers.

(2) A, a set of states of activation

There are two kinds of activation states in the CAINET: One is for the input layer; the other is for the hidden and output layers. Each unit of the input layer is further divided into two states. One represents the score of each exercise done by the student. The other represents the predicted score of the exercise which has not been done yet. The latter score is predicted and evaluated by the CAINET according to the student's learning state. In each unit of the hidden and output layer, the state of activation represents the learning state of the student. Its value ranges between 0 to 100.

(3) F, an output function

The output function of the CAINET is an identity function such that

$Y_i = F(a_i) = ai,$

$Z_j = F(a_j) = a_j,$

where
a_i is the ith unit of the input layer,
a_j is the jth unit of the hidden layer and output layer,
Y_i is the output of a_i, and
Z_j is the output of a_j.

(4) C, a set of patterns of connectivity among units, which is defined as

$$C = \{W, W', U, V\},$$

where
W is the connection between the input layer and the hidden layer,
W′ is the normalized pattern so that
$W'_{ij} = W_{ij}/W_{ij}$, for each concept j.
U is the connection between the output and the input layers. This pattern is used to predict and evaluate the score of exercises which haven't been done yet, and
V is the connection between the hidden and the output layers.

(5) T, a set of propagation rules
The propagation rule between the input layer and the hidden layer is :
$\mathrm{Net1}_j = \Sigma_i W_{ij} X_j$, where
X_i is the score of exercise i, and
W_{ij} is the connection between test i and concept j.

The propagation rule between the hidden layer and the output layer is:
$\mathrm{Net2}_j = \mathrm{Max}_i (V_{ij} * Y_i)$,

where
Y_i is the output of ith unit of the hidden layer,
V_{ij} is the connection between concept i and concept j in the hidden layer and the output layer, and
Max is used to find the maximal value of $V_{ij} * Y_i$ for all $1 \leq i,j \leq n$.

The propagation rule used to predict the score of exercises which have not been done yet is:
$\mathrm{Temp}_j = Z_j - Y_j$, for all $X_i \neq 0$,
$\mathrm{Net3}_i = X_i = \mathrm{Temp}_j * U_{ji}$, for all $X_i = 0$,

where
Z_j is the jth unit of the output layer,
Y_j is the jth unit of the output layer, and
X_i is the ith unit of the input layer.

(6) R, a set of activation rules
We then use a(t) to represent the state of the system at time t. There are four stages:

(a) $t \doteq 0$,
$a_i(0) = X_i$, where a_i is the state of the ith unit in the input layer.
$a_j(0) =$ unknown, where a_j is the state of the jth unit in the hidden layer and the output layer.

(b) $t = 1$,
$ai(1) = ai(0)$, where a_i is the state of ith unit in the input layer.
$a_j(1) = \mathrm{Net1}_j(1)$, where a_j is the state of jth unit in the hidden layer and the output layer, and Net1 has been described above in T, a set of propagation rules.

(c) $t = 2$,
$a_i(2) = a_i(1)$, where a_i is the state of the ith unit in the input layer.
$a_j(2) = a_j(2)$, where a_j is the state of the jth unit in the hidden layer.
$a_k(2) = \mathrm{Net2}_k(2)$, where a_k is the state of the kth unit in the output layer. Net2 has been described above in T, a set of propagation rules.

(d) $t = 3$,
$a_i(3) = \mathrm{Net3}_i(3)$, where a_i is the state of the ith unit in the input layer.
$a_j(3) = a_j(2)$, where a_j is the state of the jth unit in the hidden layer and the output layer, and, similarly, Net3 has been described above in T, a set of propagation rules.

(7) L, a learning rule
The learning rule of CAINET is as follows:

$$W'_{ij}(t+1) = W'_{ij}(t) + \eta * Y_j * (t_j - Y_j),$$

where
η is a constant between 0 and 1,
Y_j is the output of the jth unit of the CAINET, and
t_j is the target output of the jth unit of the CAINET.

The learning rule is based on the derivation of the generalized delta rule. It is desired that the distance between the actual and the target outputs of the CAINET is as small as possible. This distance can be defined as

$$Ep = (tp - Yp)^2,$$

where
Y_p is the actual ouput of the input pattern p and
t_p is the target output of the input pattern p.

The goal of the design is to minimize the total difference between the target output and the actual output of the system — $E = \Sigma E_p$. In the process, the normalized pattern W′ is modified each time to get a smaller E. The change of W′ can be represented as

$$\Delta p W'_{ij} \; \alpha \; \frac{\partial E_p}{\partial W'_{ij}} \quad ,$$

since

$$\frac{\partial E_p}{\partial W'_{ij}} = \frac{\partial E_p}{\partial Net_{pj}} * \frac{\partial Net_{pj}}{\partial W'_{ij}} \quad \text{, and}$$

(1)

$$\frac{\partial Net_{pj}}{\partial W'_{ij}} = \frac{\partial}{\partial W'_{ij}} \, , \sum_k \partial W'_{ij} \, X_{pk} = X_{pi} \, ,$$

where X_{pi} is the score of test i of input pattern p.

(2)

$$\frac{\partial E_p}{\partial Net_{pj}} = \frac{\partial E_p}{\partial Y_{pj}} * \frac{\partial Y_{pj}}{\partial Net_{pj}}$$

$$\frac{\partial E_p}{\partial Y_{pj}} = -(t_{pj} - Y_{pj})$$

$$\frac{\partial Y_{pj}}{\partial Net_{pj}} = F'_j(Net_{pj}) \; (\because Y_{pj} = F'_j(Net_{pj}))$$

$$\frac{\partial E_p}{\partial W'_{ij}} = -(t_{pj} - Y_{pj}) \, X_{pi}$$

$\therefore \Delta pW_{ij} = \eta * (t_{pj} - Y_{pj}) * X_{pi}$,
where η is a constant between 0 and 1.

(8) E, the environment
The system, CAINET, uses the test results to infer the student's learning state. For simplicity in this preliminary design, it is assumed that the only factors which influence the system's process are the student's test results.

III. The Construction of CAINET.

In the CAINET system, some software is written to emulate the multiprocessing system. Particularly a one-dimensional array is used to represent a set of units, and a two-dimensional array is used to represent a pattern of connectivity among units. As shown in Fig. 3, the vector Y and vector Z represent the set of concepts in different layers expressed by real numbers; the vector X represents the set of tests; and W represents an nxm weighting vector. Z_j denotes the student's degree of understanding of concept j. The values of X_j, Y_j, and Z_j are assumed to be in the interval of 0 to 100 for each j. The steps of the construction procedures of CAINET are listed as follows:

1. Specify the relation between tests and concepts by the teacher.
    a. Input {Wij} as internal representation of the CAINET
    For example, assuming the degrees of relevance between test i and concept 1, 2, and 3 are 60%, 30%, and 10%, respectively, then the weights of W are $W_{i1} = 0.6$, $W_{i2} = 0.3$, and $W_{i3} = 0.1$ as illustrated in Fig 4.
    b. Normalize the weight vector of each concept
    For each concept j, normalizing the weight vector W_{ij} as
    $W'_{ij} = W_{ij} / W_{ij}$, for each concept j. (1)
    c. Initiate the interrelation between concepts which is represented by the vector V as:
    $V_{ii} = 1$, for all concept i;

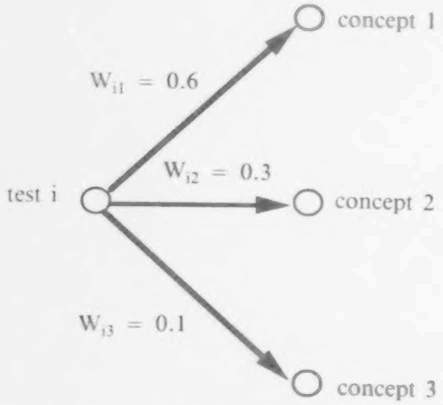


Fig. 4. The relation between test and concept

$V_{ij} = 0$, for all concept i and concept j, $i \neq j$. (2)

2. Train implicit relation between tests and concepts by teaching data and learning rule as listed below:
   a. Submit the set of training data (X_i, d_i) to CAINET, where X_i is the *i'th* test result, and di denotes the corresponding evaluation result of X_i from the teacher.
   b. Update W_{ij} by the training rule
      $W'_{ij}(t+1) = W'ij(t) + \eta * Y_j * (d_j - Y_j)$, (3)
      where η is a constant between 0 and 1; Y_j is the actual output of neuron j; and d_j is the target output of neuron j.

IV. The Illustration of ICAI/M1 System

ICAI/M1 is a prototype of an intelligent CAI system which is implemented in an Apple Macintosh Plus computer by using HyperCard. This system contains some basic materials of a college-level computer science course in data structure including pointer, stack, queue, recursion, and linked list. The architecture of the ICAI/M1 system is illustrated in Fig. 5.

The major components of this ICAI/M1 system consist of problem base, tutorial base, student module, hint and solution base, on-line help base, and hypertext man-machine interface. The problem base contains tests relating to the course material; the tutorial base contains the course materials included in an ordinary text-book; the hint and solution base contains standard answers or hints relating to exercises; the on-line help base offers system operation guidelines; the student module consists of students base and CAINET; and, the student base contains the historical information of students. In this system, CAINET provides the measurement of learning effects during the learning process.

Fig 6 illustrates the main menu which shows five instructional topics and the exercise. Note that the students who already have some knowledge of these instructional topics can choose the exercise directly.

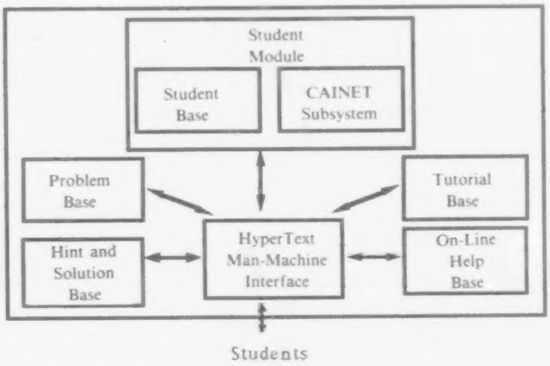


Fig. 5. The architecture of the ICAI/M1 system

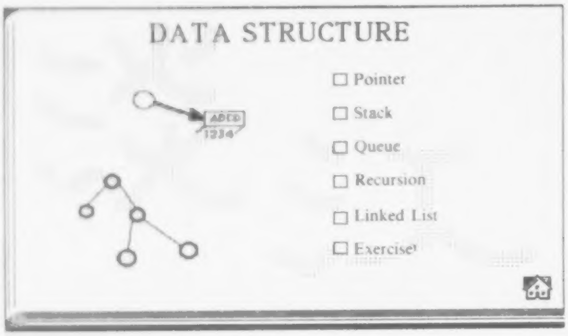


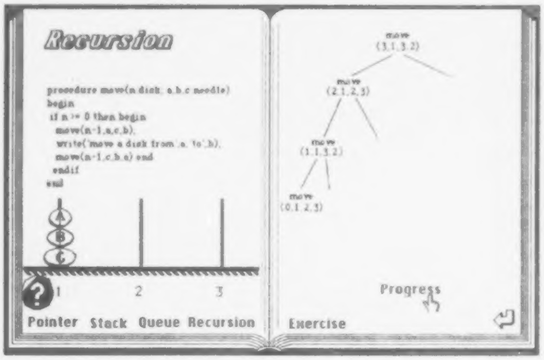
Fig. 6. The main menu screen

One of the characteristics of the ICAI/M1 system is the application of visualized algorithm processing. Step-by-step visual effects of every executed algorithm statement are provided to disclose the abstract concepts of pointers, stack recursion, and so on. For example, the algorithm of the famous Hanoi tower problem is visualized by the animation technique. Parts of the process are successively shown in Fig. 7. The plates shown on the screen actually move from one needle to another. In case the students do not understand the process, they can ask for help by touching the "question button" and the on-line help subsystem will immediately tell them how to operate the process further. A typical display panel of the on-line help screen is shown in Fig. 8.

In addition, the student can do exercises (tests) at any time that he desires. He does not have to finish all the exercises in order to obtain his learning skill. A typical screen of exercise is shown in Fig. 9. Note that the student is free to touch hint, answer, and the evaluated grade. For instance, when the "Your Grade" button is pressed, the ICAI/M1 will tell the student his score and those concepts that he needs to improve if he intends to apply his current learning skill in solving those questions which he has not yet attempted. The operation is shown in Fig. 10. The fulfillment of this essential work is carried out by CAINET.

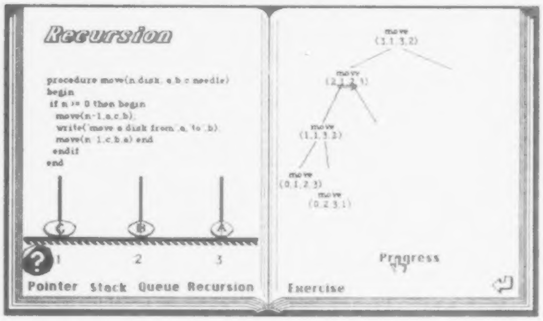
V. Conclusion

This paper presents a prototype of an ICAI system which adopts some topics of a college-level computer science course in data structure: pointer, linked list, queue, stack and recursion as teaching subjects. A novel neural network model called


Recursion
A
B
C
1
2
3
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (1,1,3,2)
move (0,1,2,3)
Progress
Exercise

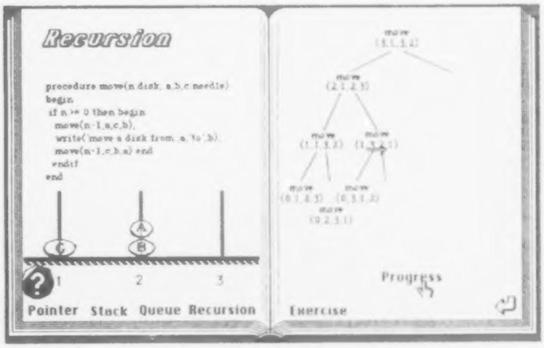
```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
  move(n-1,a,c,b);
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (a)


Recursion
C
B
A
1
2
3
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (1,1,3,2)
move (0,1,2,3)
move (0,2,3,1)
Progress
Exercise

```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
  move(n-1,a,c,b);
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (b)


Recursion
A
C
B
1
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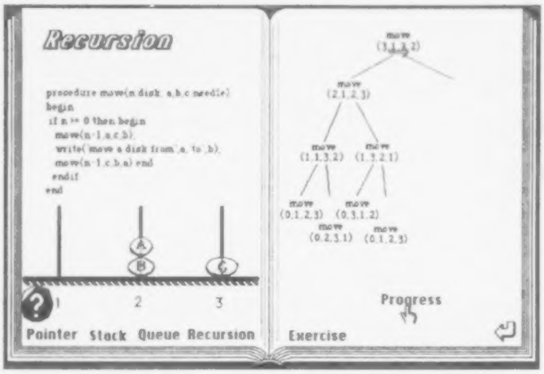
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (1,1,3,2)
move (1,3,2,1)
move (0,1,2,3)
move (0,3,1,2)
move (0,2,3,1)
Progress
Exercise

```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
  move(n-1,a,c,b);
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (c)


Recursion
A
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1
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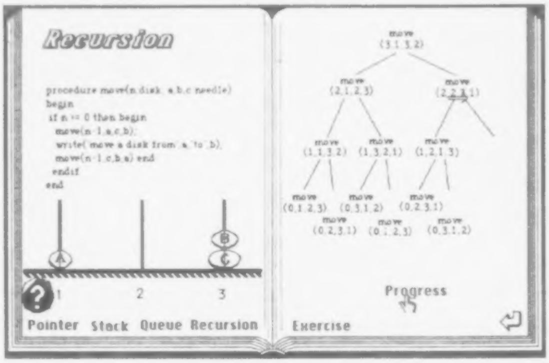
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (1,1,3,2)
move (1,3,2,1)
move (0,1,2,3)
move (0,3,1,2)
move (0,2,3,1)
move (0,1,2,3)
Progress
Exercise

```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
  move(n-1,a,c,b);
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (d)


Recursion
A
B
C
1
2
3
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (2,2,3,1)
move (1,1,3,2)
move (1,3,2,1)
move (1,2,1,3)
move (0,1,2,3)
move (0,3,1,2)
move (0,2,3,1)
move (0,2,3,1)
move (0,1,2,3)
move (0,3,1,2)
Progress
Exercise

```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
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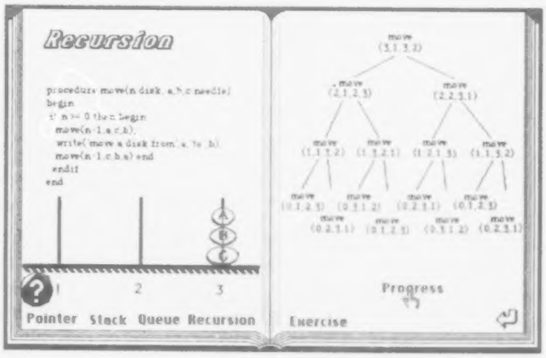
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (e)


Recursion
A
B
C
1
2
3
Pointer Stack Queue Recursion
move (3,1,3,2)
move (2,1,2,3)
move (2,2,3,1)
move (1,1,3,2)
move (1,3,2,1)
move (1,2,1,3)
move (1,1,3,2)
move (0,1,2,3)
move (0,3,1,2)
move (0,2,3,1)
move (0,1,2,3)
move (0,2,3,1)
move (0,1,2,3)
move (0,3,1,2)
move (0,2,3,1)
Progress
Exercise

```
procedure move(n disk; a,b,c needle)
begin
 if n >= 0 then begin
  move(n-1,a,c,b);
  write('move a disk from',a,' to',b);
  move(n-1,c,b,a) end
 endif
end
```

Fig. 7. (f)

CAINET is developed, which constitutes the core of this ICAI system. The purpose of CAINET is to infer the learning state of students. This ICAI system is the first model of our ICAI development and is called ICAI/M1. In summary, the ICAI/M1 system has the following characteristics:

1. Individualization
   It is able to infer the learning state and respond to requests by the individual student.
2. Comprehensiveness
   The inferential neural net model emulates the decision process of a teacher in two ways: the natural reduction by training with teaching data and the induction by specifying the explicit weight of the neural net.
3. Fault tolerance

BEST COPY AVAILABLE

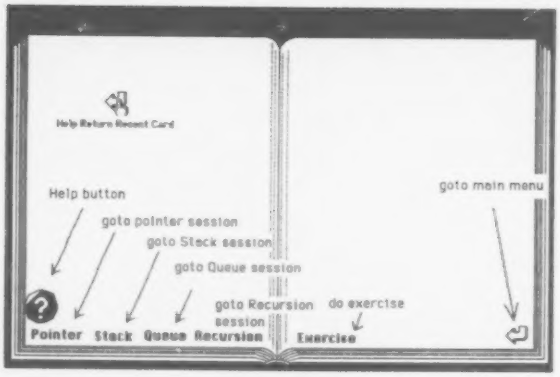
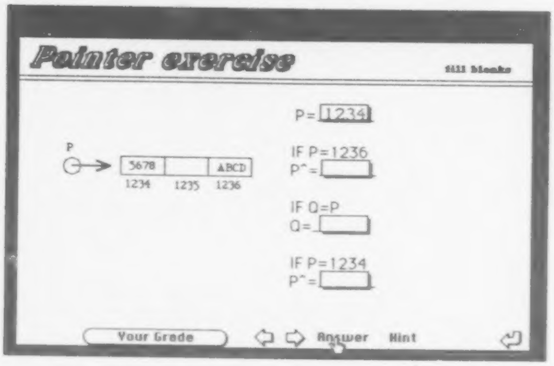

Help Return Recent Card
Help button
goto pointer session
goto Stack session
goto Queue session
goto Recursion session
do exercise
goto main menu
?
Pointer
Stack
Queue
Recursion
Exercise

Fig. 8. On-line help screen.


Pointer exercise
fill blanks
P
5678
ABCD
1234
1235
1236
Your Grade
Answer
Hint

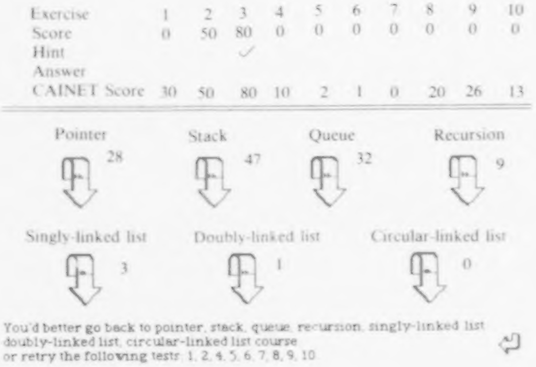
P=1234

IF P=1236
P^=

IF Q=P
Q=

IF P=1234
P^=

Fig. 9. One of exercises to learn pointer.



Exercise	1	2	3	4	5	6	7	8	9	10
Score	0	50	80	0	0	0	0	0	0	0
Hint			✓							
Answer										
CAINET Score	30	50	80	10	2	1	0	20	26	13

Pointer
28
Stack
47
Queue
32
Recursion
9
Singly-linked list
3
Doubly-linked list
1
Circular-linked list
0

You'd better go back to pointer, stack, queue, recursion, singly-linked list
doubly-linked list, circular-linked list course
or retry the following tests: 1, 2, 4, 5, 6, 7, 8, 9, 10

Fig. 10. The learning state of a student.

When a student gives a correct answer for a test problem, it is possible that he receives the "lucky strike". That is, test results may contain some random answers which are viewed as faults. The proposed system is able to infer student learning state with limited amount of faults in test results.

4. Encoding expert's knowledge naturally
   Things required for a teacher to build the inferential neural net are to describe the relations between tests and concepts, the interrelation between concepts, and examples of testing results and the corresponding student's learning state. Using the ICAI/M1 system, it is very easy for a teacher to implement his (her) model without needing any pre-knowledge.

In addition to the advantages mentioned above, the ICAI/M1 system is also an open and student-oriented CAI system. Consequently, we believe that the results of this study have laid a solid foundation for the further development of a matured ICAI system.

V. References

Atkinson, R. C. (1972). Ingredients for a theory of instruction. *American Psychologist, 27,* 921-931.

Carpenter, G. A. (1989). Neural network models for pattern recognition and associative memory. *Neural Network, 2,* 243-245.

Goodman, Danny (1987). *The complete HyperCard handbook.* Toronto: Bantam.

Grossberg, Stephen (1988). Nonlinear neural networks: principles, mechanisms, and architectures. *Neural Networks, 1,* 17-61.

Kaehler, Carol (1988). *HyperCard power techniques and scripts.* Reading, Massachustts: Addison-Wesley.

Lippmann, R. P. (1987). An introduction to computing with neural nets. *IEEE ASSP Magazine,* 2-22.

McClelland J. L. & Rumelhart, D. E. (1987a). *Parallel distributed processing, Vol I.* Cambridge, Massachusetts: MIT Press.

McClelland J. L. & Rumelhart, D. E. (1987b). *Parallel distributed processing, Vol II.* Cambridge, Massachusetts: MIT Press.

McCombs, B. L. & McDaniel, M. A. (1981). On the designs of adaptive treatments for individualized instructional systems. *Educational Psychologist, 16,* 11-22.

Park O. C. & Tennyson, R. A. (1983). Computer-based instructional systems for adaptive education: a review. *Contemporary Education Review, 2,* 121-135.

Park, O. C. (1982). A response-sensitive strategy in computer-based instruction. *Journal of Educational Technology System, 10,* 187-197.

Takeuchi, A. & Otsuki, S. (1986). Method for inferring a student model in ITS. *Proceedings of International Computer Symposium 1986,* 211-218.

Tennyson, R. D. & Christensen, D. L. (1984). The Minnesota adaptive instructional system: an intelligent CBI system. *Journal of Computer-Based Instruction, 11,* 4-13.

以類神經網路方法設計智慧型電腦輔助教學系統

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摘　　要

本文引用類神經網路技術來推論學生之學習狀態，以建立一套開放式並以學生爲導向的智慧型電腦輔助教學系統，此系統之運作機能因係採用學生學習一種觀念的練習結果做爲預測學習狀態的輸入，故是可以訓練的。爲引證前述理念之可行，本文纔以大學之資料結構爲教材，在蘋果牌微電腦上發展出一套雛型系統，結果顯示本系統具有個別化、易理解、易編碼及容錯的特色。

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A Comparison of Curriculum and Career Choices of Vocational High School Students in the United States and Taiwan, R.O.C.

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ABSTRACT

While considerable research efforts have been made to identify factors which influence high school-age students in making curriculum and career choices, little attention in research has been directed to the cultural variable and impacts on such decisions.

This study included a cross-cultural comparison of curriculum and career decisions made by high school students in vocational programs in Taiwan and the United States.

Comparisons were made regarding a) curriculum choice, b) career choice, c) prospect of employment upon graduation, d) perception regarding continued education and training, and e) work experience.

Significant differences were found and the results confirmed that country or culture is a dominant factor which influences student perceptions, expectations and choices.

Key words: curriculum choices, career choices, vocational student, international education, continued education

I. Introduction

When a decision to enroll in a vocational or nonvocational high school program needs to be made, such a decision apparently is influenced by both the school curriculum experiences and career development interest of the student (MSDE, 1989). This decision in making tentative choices with regard to individual curriculum and career, which may have a short- or long-term effect (Copa & Salem, 1981) to the students, represents no easy task. Research results found by researchers suggest that these influential factors are complex and interrelated.

However, an absence of understanding of the factors which influence such choices and their effects upon diverse cultural background and educational systems prevalently exists as is reflected in several studies. This study attempted to ascertain the degree of knowledge of factors influencing curriculum and career choices by comparing differences between senior high school students in the United States with students in Taiwan regarding these selected factors.

Factors most affecting high school students in making their curriculum and career choices have been documented in a great number of studies. Among the factors frequently listed are influential persons, academic performance, intrinsic reasons, aspirations and expectations toward the curriculum and career. The following discussion narrates these factors in detail.

Influences from personnel are well known as one of the external, influential factors. Parental influences have been reported to be the most effective along with influence from peers, friends, and teachers (Alden & Seiferth, 1979; Harrison & Kotrlik, 1989; Kendall & Miller, 1983; Sube, 1981; Vetter *et al.*, 1979; Young, 1985) while guidance services were the least effective (Alden & Seiferth, 1979; Kendall & Miller, 1983; MSDE, 1989). Specifically, Stone and Wang (1990) discovered that the father and the father's occupation have a positive influence while a negative influence from the mother and her occupation was reported. Additionally, Young (1985) reported that mothers have a most significant influence on the daughter's choice while the fathers have a most significant influence on the son's choice. Seemingly, sex stereotyping interacts with parental roles to a certain degree thus influencing the student's decision-making toward career selection.

This interaction is also evident in the selection process of vocational programs. Kendall and Miller (1983) depicted that students in both traditional and nontraditional vocational programs received more support from the mother than other individuals. However, students in vocational programs have received less support and larger resistance from their parents than students in nonvocational programs (MSDE, 1989), owing to the curriculum or programs selected. Essentially, the students were encouraged by parents to go to college after high school education.

Support or resistance are also proposed by other personnel such as peers, friends, teachers, or counselors (Kendall & Miller, 1983; MSDE, 1989). Results of the review of research indicate that, as an information source, career and curriculum counselors were found providing poor or no services to the students (Alden & Seiferth, 1979; Kendall & Miller, 1983; MSDE, 1989). Interestingly, students who waited or delayed taking vocational programs, consider themselves as the most instrumental in making this decision (Kendall & Miller, 1983; MSDE, 1989).

Other than influences from personnel, some factors are more intrinsic: role model, sex stereotype, individual interests, and ability are contributing factors which influence students in making their curriculum and career choices to a certain degree. Students readily see their parents as role models which explains parental encouragement or discouragement being a high influence toward nontraditional career choices (Young, 1985). The long-standing sex stereotype also places a significant influence on students' career choices (Alden & Seiferth, 1979; Young, 1985) or enrollment in a vocational program (Vetter *et al.*, 1979). Vetter and his co-workers (1979) found that occupational sex segregation and related wage disparities are perpetuated although there is an increase of women in nontraditional occupations. Moreover, individual interests and ability are vital in influencing career and curriculum decision making, according to Harrison & Kotrlik (1989) and Vetter *et al.* (1979).

On the other hand, basic ability was found to be the major contributor to academic performance in terms of grade point average (Camp & Smick, 1988). The study results state that the dropout rate of students in vocational programs is three times that reported in nonvocational programs (MSDE, 1989). It has been speculated that a socioeconomic status factor may have an influence on students' academic performance and further decisions in curriculum and career selection (Camp & Smick, 1988; Grimes & Scalise, 1986) although it remains insufficient and inconclusive documentation. In addition, Noeth et al. (1984) provided support in which the course work identified to be interesting is very helpful in occupational decision making. However, the study did not identify which courses were thought to have been influential.

Another influential factor in making decisions for curriculum and career choices is occupational aspiration and expectation (MSDE, 1989). The study indicated that students enrolled in vocational education are more likely to decide on a career area before graduation. Furthermore, students, whether or not enrolled in traditional or non traditional vocational programs, have a positive perspective and attitude toward the programs or career chosen (Kendall & Miller, 1983). Nevertheless, Camp & Smick (1988) pointed out that enrollment in vocational programs produces reduced occupational aspiration among students when correcting for the effects of gender, socioeconomic status, basic ability, and high school GPA, as pointed out by Camp & Smick (1988). Interestingly, students in both college preparatory and vocational programs displayed a willingness to make the same curriculum and career choices (Kendall & Miller, 1983; MSDE, 1989). Furthermore, Stone (1988) and Stone & Wang (1990) found that participation in vocational programs was positively associated with higher job status attainment by marketing students but was unassociated with career aspirations.

In addition, sex as a socialization factor has been correlated to individual career aspiration and expectation. Young (1985) reported that sex stereotyping vigorously interacts with parental roles to a certain degree as influencing students' decision-making toward career selection. In contrast to Farmer's findings (1983), Koski & Subich (1985) reported no differences were found among female and male in career or home commitment. However, the study concluded that females keep suffering from sex segregation existing in the society no matter how strong their commitment toward the career they might have.

Similar reasons influencing curriculum and career choices were found in studies (Harrison & Kotrlik, 1989; Kendall & Miller, 1983; MSDE, 1989). Among these factors are: program sounded interesting, need or want to be prepared for a job after high school, prefer practical learning experiences, desire to learn vocational-technical skills, availability of jobs in this field, and working conditions, salary or wages.

II. Statement of the Problem

While considerable research efforts have been made to identify factors which influence high school-age students in making curriculum and career choices, little attention has been directed to study the cultural variables and impacts on such decisions.

The intention raised then is whether cultural background and the educational system affect high school students in making curriculum and career choices in one nation differently from another.

III. Population and Sampling

The population identified for this study included essentially those high school students who enrolled in voc-ed programs. Students in Taiwan were selected based on vocational high schools in which they participate. The vocational high schools were randomly selected by county and city, including public and private schools. The selected students from these schools were referred to as ROC students throughout this report.

Subjects for this study in the U.S.A. were drawn from the student population that enrolled in comprehensive secondary schools and participated in vocational education programs. State directors were consulted to provide school lists on which relatively comprehensive vocational educational programs are offered by the schools. Ultimately, ten states were selected to participate this study: California, Georgia, Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, and Oklahoma. This sample contained students who were referred to as USA students. In this study, 1,477 out of 2,000 ROC students and 745 out of 1,000 USA students provided the data for analysis.

The self-administered questionnaire method was employed to collect data for this study. English and Chinese versions of the questionnaire were developed. Considerable effort was expended to make the questionnaires equivalent.

Because of systems differences, where ten percent of the item was incomplete, the item was omitted from analysis.

IV. Research Hypotheses

Five hypotheses were posed for this study to determine what factors influenced high school students' curriculum and career choices in Taiwan and the U.S. The five hypotheses are:

1. There is no difference in the factors which influence curriculum choice between the Chinese and the United State students enrolled in secondary vocational education programs.
2. There is no difference in the factors which influence career choices between the Chinese and the United State students enrolled in secondary vocational education programs.
3. There is no difference in students' perceptions of the prospect for finding employment upon graduation between the Chinese and the United States students enrolled in secondary vocational education programs.
4. There is no difference in students' perceptions toward continued education and training between the Chinese and the United States students enrolled in secondary vocational education programs.
5. There is no difference in work experience between the Chinese and the United States students enrolled in secondary vocational education programs.

V. Data Analysis

Two statistical methods were applied to analyze the data. Chi-square statistics were used to examine differences between countries and each item (for the content of the items refer to Table 1). To further analyze the data, the log linear model was employed to cross-examine several variables of interest. All tests were evaluated at .05 level of significance.

VI. Findings

Findings from this study were divided into two parts. Part 1 referred to summary analysis for one item at a time, which in effect summarized the results from chi-square tests for differences in each item by country. Part 2 reported findings from a cross-evaluation of several variables using the log linear model. The multiple variate analysis used in Part 2 provides an insight of variations which account for variables other than the country variable.

Part 1. Summary Analysis for One Item at a Time

Based on results from chi-square tests, factors which influence curriculum (Table 2) and career

Table 1. Brief Description of Item Content

ITEM	DESCRIPTION	ASPECT
6	sister/brother from voc-ed	personal influence
12	relatives from voc-ed	ditto
15	reasons to study voc-ed	ability & prospect
16	personal influence	personal influence
17	self-rating	self-image
18	prospect of curriculum	prospect
19	influential factor	ability
20	program rating	program
21	means of building self-image	self-image
22	source of information	source
23	adequate information	source
24	influence to career choice	career influence
25	help to career choice	source
26	job preference career	influence
27	difficulty of making career choice	influence
28	continue same voc-ed program	continue educaiton
29	location of first job	job preference
30	time period prior to promotion	prospect
31	job in neighborhood	job preference
32	criteria for job selection	job preference
33	company preference	job preference
34	immediately continue education	continue education
35	deferred continue educaiton	continue education
36	participation of paid training	continue education
37	needs for continued education	continue education
38	summer work experience	work experience
39	cooperative work experience	work experience
40	work in relation to choices	work influence
41	work contribution to curriculum	work influence
42	work contribution to career	work experience
43	work reinforcement to study	work experience
44	making same curriculum choice	
45	making same career choice	
46	optimistic prospect of employment optimism	optimism
47	helpfulness of subject to success ability	ability
48	helpfulness from curriculum	self-image
49	activities outside of class	work experience
50	remaining in high school	program

choices (Table 4) as well as subjects with higher probability by country (Tables 3, 5, 6, 7, and 8) were summarized as follows.

Hypothesis 1

There is no difference in factors which influence curriculum choice between the Taiwan and the USA students enrolled in vocational education programs.

Results reported in Table 2 indicate the high school students in vocational education within Taiwan and USA, are influenced by different factors in making their curriculum choice. Parental influence on curriculum choice is more prevalent with the R.O.C. student.

Students were also asked to rate self-perception and subject preference related to curriculum choice.

Student perceptions of self did differ by country as indicated in Table 3. R.O.C. students

1981

Table 2. Factors Which Influence Curriculum Choice

R.O.C.	U.S.A.
Want to do technical work.	Ability to succeed in technical subjects.
Influence by relatives or parents.	Influence by counselors or teachers.
Gain knowledge & skills to solve technical problem.	See a good future for technical curriculum graduates.
Saleable skills & knowledge needed for employment.	A satisfying & fulfilling life style.
	Start a business & be in charge.
Interest in working with practical problem and activities.	Ability to succeed in practical subjects.
Lack of interest/motivation in academic subjects.	Preference for particular type of work.

Table 3. Reported Subjects Higher Probabilities by Country — In Relation to Curriculum Choice

R.O.C.	U.S.A.
Rate themselves moderately able or weak.	Rate themselves exceptionally able or able.
Build self-image by means of parental satisfaction or teacher's praise.	Build self-image by means of self-confidence or success from study.
Would not make same curriculum choice.	Would make the same curriculum choice again.
Science is most helpful to succeed.	Mathematics is most helpful to succeed.
Success in curriculum help to build a good self-image.	
Will not remain in senior high school if voc-ed program is not available.	Will remain in senior high school if voc-ed program is not available.

perceived science as most essential to succeed in vocational education, whereas U.S.A. students rated mathematics as most helpful to succeed. Taiwan students tend to build their self-image by means of parental satisfaction and teacher's praise while U.S.A. students do so by means of increase in self-confidence or success from study.

It can be summarily stated that students in Taiwan and the United States consider different factors in making a curriculum choice. As reported in previous studies (Basu *et al.* 1990) the nation is a determining variable.

Hypothesis 2

There is no difference in the factors which influence curriculum choice between the Taiwan and the United States high school students enrolled in vocational education.

Results reported in Table 4 indicate the high school students in vocational education within Taiwan and U.S.A. are influenced by different factors in making career choices. Information to make career choices comes from different sources. R.O.C. students get information from parents, teachers and classmates while U.S.A. students gain information from counselors, exploratory experiences and previous work experience.

Other variables were examined which influence career choice as listed in Table 5.

The Taiwan student encounters more difficulty in obtaining adequate information to make a career choice than does the U.S.A. student. While R.O.C. students prefer careers in manufacturing or government service, U.S.A. students prefer military or service work.

There are differences between the factors

Table 4. Factors which Influenced Occupational/Career Choice

R.O.C.	U.S.A.
Parents and teacher as source of information.	Counselors as a source of information.
Good prospects of employment.	Adequate information and exploratory experience.
Encouragement from introductory voc-ed courses.	Prospect for earning a good income.
The type of work vocational education students would do.	Influence of previous work experience.
Influence of classmates.	
Continue with the same voc-ed program beyond high school activities.	

Table 5. Reported Subjects Higher Probabilities by Country — In Relation to Career Choice

R.O.C.	U.S.A.
Obtain information from teacher to make career choice.	Obtain information from counselors, employment opportunity information, or other source to make career choice.
Cannot obtain adequate information to make curriculum choice.	Obtain adequate information to make curriculum choice.
Prefer manufacturing or government service.	Prefer military service or service work.
Make career choice with moderate difficulties.	Make career choice with no difficulties.
Will continue in the same type of program in advanced study.	Will not continue in the same type of program in advanced study.

Table 6. Reported Subjects Higher Probabilities by Country — In Relation to Career Outlook (Employment Opportunities)

R.O.C.	U.S.A.
Expect to obtain the first job upon graduation wherever the right job is available.	Expect to obtain the first job somewhere in home state.
Expect to get promoted within 1-3 three years at work.	Expect to get promoted within 4 or more years at work.
Will not accept a job in neighborhood with lower wages but training field related.	Will accept a job in neighborhood with lower wages but training field related.
Select job that provides creative or challenging work.	Selected job that the initial wage or the opportunity for advanced training is high.
Prefer to work for old company.	Prefer to work for small company.
Are not optimistic or uncertain about gaining employment upon graduation.	Are very optimistic about gaining employment upon graduation.

Table 7. Reported Subjects Higher Probabilities by Country — In Relation to Continued Education

R.O.C.	U.S.A.
Intend to continue education immediately after graduation.	Intend to work a while then continue education after graduation.
Will participate in paid inplant training or evening classes.	Uncertain about the participation fo paid in-plant training.
View the need for continued education.	Uncertain or view no need for advanced education.

Table 8. Reported Subjects Higher Probabilities by Country — In Relation to Work Experience

	R.O.C.	U.S.A.
Have summer work experience.	N	Y
Have work experience that is cooperative education related.	N	Y
Previous work experience is related to curriculum and career choices.	N	Y
Work experience contributes to remaining in voc-ed program and insights as a future worker.	N	Y
Work experience reinforces and expands study in voc-ed program.	Y	Y

Key: N — no
Y — yes

which influence career choices of R.O.C. and U.S.A. vocational education students.

Hypothesis 3

There is no differnece in students' perceptions of the prospect of finding employment upon graduation between R.O.C. and U.S.A. students enrolled in vocational education.

There are differences between the R.O.C. & U.S.A. students' perceptions regarding the prospects for finding employment upon graduation. R.O.C. students are willing to assume employment wherever the job is available, where work is challenging and preferably an old company.

U.S.A. student prefers to work in one's state, a job related to training, opportunity for advance training and preferably a small company.

Hypothesis 4

There is no difference in student's perceptions toward continued education and training between the R.O.C. and U.S.A. students enrolled in vocational education.

The R.O.C. students anticipate continuing their education and training after graduation to a greater extent than the U.S.A. students.

However, both groups of the students recognize the need for continuing their education even if they have to work for a while prior to re-entry into education.

Hypothesis 5

There is no difference in work experience between the Chinese and United States students enrolled in secondary vocational education programs.

The differences between the two samples of students is perhaps the most pronounced regarding this specific hypothesis.

It was estimated by Ralph Tyler that eighty percent of high school students in the U.S. have experienced paid work experience by high school graduation. Perhaps this proportion is even higher for vocational education because ten percent of the vocational education students also participate in cooperative education.

VII. Summary

There were differences between the two sample groups of vocational education students from R.O.C. and U.S.A.

Curriculum

R.O.C. students maintain that interest and desire to work with technical subjects are two major reasons for their curriculum choice.

U.S.A. students listed ability to succeed and seeing a good future are their main reasons for curriculum choice. R.O.C. students seem to perceive more influence from their parents, relatives, than do U.S.A. students in making career choices.

U.S.A. students are more likely to be influenced by counselors and their exploratory experiences in industrial arts in making their curriculum choice.

There was limited influence from teachers on curriculum choice.

Careers

For R.O.C. students, teachers and parents were two major sources of information to help them make career choices.

U.S.A. students rely on information and advice from counselors and other individuals rather than parents to help them make their career choice. U.S.A. students also look for employment opportunity information when they are making their career choices.

Employment Prospect

U.S.A. students prefer to find employment in their own state. R.O.C. students are willing to go wherever there are job opportunities.

U.S.A. students will consider high initial wage in their job selection, while R.O.C. students are more likely to select a job that is creative and challenging. R.O.C. students prefer to work for an old company, while U.S.A. students prefer to work for a small company.

U.S.A. students were more optimistic about their employment opportunity upon graduation than the R.O.C. students. U.S.A. students' having had previous work experience may have contributed to their confidence of securing employment upon graduation.

Continued Education & Training

R.O.C. students are more likely than the U.S.A. students to continue their education after high school graduation. However, they are less likely than the U.S.A. students to participate in in-plant training.

Differences in Work Experience

There was a significant difference between the two sample groups of students. U.S.A. students are more likely than R.O.C. students to have summer or cooperative experience.

It is very clear that the country or culture is a variable which does interact with the factors examined. In planning, implementing or evaluating vocational programs, the context or country where programs operate cannot be overlooked as a cultural aspect by vocational curriculum planners.

References

Alden, E. F., & Seiferth, B. B. (1979). *Factors influencing choice of technical careers by women and minorities.* (ERIC ED 188656).

Basu, C. K. Espino, I. G., & Lane, T. G. (1990). *The influence of teacher attitudes on the schooling of girls in technical/vocational education in the Asian Pacific region.* UNESCO pb. Colombo Plan Staff College for Technical Education, Musalco Avenue, Dasia, Metro Manila, Philippines.

Camp, W. G., & Smick, R. A. (1988). *Vocational enrollment patterns and occupational aspirations of American high school students in 1982.* (ERIC ED 307394).

Copa, G. H., & Smick, R. A. (1988). *Stability in job selection patterns of post-secondary vocational education graduates in Minnesota.* (ERIC ED 211844).

Farmer, H. (1983). Career and homemaking plans for high school youth. *Journal of Counseling Psychology, 30,* 40-45.

Grimes, J. W., & Scalise, J. J. (1986). *An analysis of variables affecting high school students' vocational choices.* (ERIC ED 284008).

Harrison, B. C., & Kotrlik, J. W. (1989). Career decision patterns of high school seniors in Louisiana. *Journal of Vocational Education Research, 14*(2), 47-65.

Kendall, E. L., & Miller, L. E. (1983). Attitudes toward school preparation of nontraditional and traditional vocational education completers. *Journal of Vocational Education Research, 83,* 33-45.

Koski, L. K., & Subich, L. M. (1985) Career and homemaking choices of college preparatory and vocational education students. *Vocational Guidance Quarterly, 34*(2), 116-123.

MSDE (1989). *Survey of Massachusetts high school students: program enrollment decisions, high school experiences, career plans and post high school plans, and opinions about vocational-technical education.* (ERIC ED 313562).

Noeth, R. J., Engen, H. B., & Noeth, P. E. (1984). Making career decisions: A self-report of factors that help high school students. *Vocational Guidance Quarterly, 32,* 240-248.

Stone, J. R.. (1988). The contributions of vocational education to career aspirations, work attitudes, and academic achievement in high school. *Journal of Vocational Education Research, 13*(1).

Stone, J. R., & Wang, Y. (1990). The influence of participation in vocational education on expressed career choice in a related occupation. *Journal of Vocational Education Research, 15*(1), 41-54.

Sube, H. (1981). *Choice of profession, vocational training,*

occupation and work. (ERIC ED 202661).

Vetter, L. *et al* (1979). *Factors influencing nontraditional vocational education enrollments: A literature review.* Columbus, OH: The National Center for Research in Vocational Education, The Ohio State University. (ERIC ED 181326).

Young, P. M. (1985). *The influence of parents on the educational and occupational decision making of their children: reducing sex role stereotyping in vocational education.* (ERIC ED 277813).

中美高級中學學生課程與生涯選擇之比較研究

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摘　要

由於生涯教育的興起與推行，有許多學者已重視高級中學學生之課程與生涯選擇之研究，但在目前之研究文獻中，卻很少有人進行文化中背景因素對學生課程與生涯選擇影響之研究。

本研究係針對以上問題而進行泛文化之比較研究，探討中美高級中學階段學生的生涯選擇之異同，本研究主要探討以下之幾項重點：①課程選擇，②生涯選擇，③畢業後之就業意願，④畢業後接受進一步教育或訓練之意願，與⑤工作經驗。

爲達到以上之研究目的，分別由研究者在台灣省高級職業學校分層抽取2000位學生及在美國抽取1000位學生爲樣本進行問卷調查，綜合台灣1477份及美國745份之資料，分析後發現國別與文化背景的差異的確影響高中學生的課程與生涯之看法、期望與選擇。

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Junior High School Students' Alternative Frameworks of Heat and Temperature

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ABSTRACT

The main purpose of this study was to investigate alternative frameworks of heat and temperature among both eighth-grade and seventh-grade students. The former had received formal instruction in the selected topics at the junior-high-school level, while the latter had not. An alternative framework was a domain-specific underlying explanatory model capable of explaining the occurrence of certain alternative conceptions which were shared by many students. A two-stage research design involving a paper-and-pencil test and a clinical interview was adopted in this study in order to identify students' alternative conceptions of heat and temperature, that is, conceptions which were opposed to or failed to fit into an accepted pattern of scientific explanation as offered by the standardized physical science textbook. The subjects interviewed included six eighth-grade students and an equal number of seventh-grade students. They were chosen purposely from two classes with a total of 106 students, whose alternative conceptions on heat and temperature had been identified by analyzing their responses to the paper-and-pencil test. The technique of interview-V developed by Ault, Novak, and Gowin was followed in this study for the reduction, analysis, and synthesis of data obtained from the interview. Students' alternative conceptions of heat and temperature obtained from analyses of both the written test and the clinical interview were crosschecked and combined. A close examination of the nature and the physical meanings of these alternative conceptions suggested the existence of the following alternative frameworks:

1. Absence of the concept of thermal equilibrium.
2. Confusion between heat and temperature.
3. Heat as a material substance.
4. Passive roles of molecules when an object was heated.

Key words: alternative frameworks, conceptions, heat, temperature, clinical interview

I. Introduction

Since the early 1970s research in science education began to focus on students' conceptions and learning in specific science domains such as force, motion and so on (Driver and Erickson, 1983; Gilbert and Watts, 1983; White, 1988; Driver, 1989). Instead of focusing on general logical capabilities, researchers began to emphasize the investigation and description of the ways in which students seek to make sense of a range of natural phenomena, and to consider the implications for instruction and curriculum development in science. The research findings from these studies indicate that students bring to their science classes ideas, expectations, and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences, and that students' conceptions in science may differ substantially from the generally accepted pattern of scientific explanations taught at school. Various terms including "misconceptions," "erroneous concepts," "mistakes" and so on, have been used by researchers to describe this kind of knowledge (Abimbola, 1988; Gauld, 1987), but it will be referred to as *alternative conceptions* consistently in the following. Students' alternative conceptions were also found to influence their further learning in science, and to be resistant to change through traditional instruction.

In order to explain what is meant by the term "alternative framework", it is necessary to mention that in recent years a constructivist view of learning is gaining wider acceptance by researchers in science education. The constructivist perspective on students' learning of science has been described in detail by a number of authors including, for instance, Bodner (1986), Wittrock (1986), Driver and Bell (1986), Novak (1988), Hodson (1988), Cleminson (1990), Duschl (1990), Tobin (1991), and Wheatley (1991). Central to this broadly-conceived constructivist perspective is that knowledge is not passively received, but is actively built up by the cognizing subject; and that the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality (Wheatley, 1991). With regard to students' learning of science, the constructivist view recognizes the importance of the domain-specific conceptual frameworks that students construct from their personal experiences of the world around them. A "conceptual framework" (or framework, for short) is a set of concepts, expectations, beliefs, and rules that students use to make sense of a range of natural phenomena, and to make inferences and predictions about new situations. In contrast with the terms "conception", "misconception", or "preconception" which mainly refer to a particular or concrete event, a "conceptual framework" is an abstract, explanatory model that students constructed in order to represent the world according to their own observation and interpretation (Head, 1986). Apparently, the adjective "alternative" applies when it fails to fit into an accepted scientific explanation.

Speaking in terms of students' alternative framework is consistent with the constructivisit viewpoint that knowledge is relative and tentative. it avoids the negative connotation of the term "misconception", which is more in line with the traditional empiricist view that scientific knowledge is absolute truth. In additon, the term "alternative framework" generally refers to a framework which is shared by many students (Gilbert and Watts, 1983; Driver and Easley, 1978; Driver, 1981). This is not an unusual requirement because there have been repeated research findings as noted, for instance, by Piaget (1971) and Marton (1981), that phenomena and aspects of reality are often experienced or conceptualized in a relatively limited number of qualitatively different ways. That is, in between the common and the idiosyncratic there seems to exist a level of models of experiences, or forms of thought, which is worthwhile studying. The focus of investigating and describing the alternative conceptual frameworks commonly shared by many students in a particular science domain is of particular interest and significance from an instructional point of view. Knowing students' alternative frameworks is the first step toward a better instructional design which will possibly bring about conceptual change in students. Also, it would be quite hopeless trying to help students change their conceptions in science if each student in a science classroom were to have an idiosyncratic alternative framework of his own.

Although the study of students' alternative frameworks in science has been very active in western countries during the past decade, similar types of research began to occur in Taiwan only a few years ago. Realizing the educational importance and the novelty of the research methods, researchers in Taiwan are now conducting this kind of study about a number of selected science topics for students at all levels in Taiwan. The author, with many graduate students under his supervision, has carried out a number of research studies in this direction. The works reported here dealt only with the investigation of alternative frameworks on heat and temperature for junior high school students.

Since related literature has been extensively reviewed elsewhere (Guo, 1988, 1990a, 1990b), it will not be repeated here. It is, however, worthwhile pointing out that an effort has been made in the above to clarify the definition of the term "alternative framework", and with that, a procedure in data collection and data analysis was introduced in this study in order to justify the identification of students' alternative frameworks. This is perhaps in a small way, a contribution to research in this area. The research methods used in this study will be described in Section II, while results and discussions will be given in Sections III and IV, respectively.

II. Methods

The identification of students' alternative frameworks calls for special attention to the methods of data collection and data analysis. In order to probe deeply into students' perceived world of reality, while at the same time attempting to find alternative conceptions which were shared by many students, the author has come up with a two-stage research design. It consisted of a paper-and-pencil test which was at first administered to a larger sample, say one hundred students or so, and a follow-up in-depth interview with a smaller number of students who were selected purposely from the subjects who had taken the paper-and-pencil test previously. A flow chart for the research procedures is shown in Fig. 1. Details regarding the development of the paper-and-pencil test and interview schedules, the selection of interview subjects, and the procedures of data collection and data analysis are discussed in the following.

1. Development of instruments

The instruments used for data colleciton in this study included a paper-and-pencil test and some interview schedules. The development of these instruments was based on a conceptual structure which underlies the related topics on heat and temperature appearing in the standardized junior-high physical-science textbook, and so were the analysis and interpretation of the data collected. Details for the development of such a conceptual structure and of the instruments are given below.

(1) Constructing an idealized conceptual structure

An idealized conceptual structure showing the key concepts, principles and theories about heat and temperature is given in Fig. 2. This was obtained from an analysis of the mateirals covered by the standardized junior high physical science textbook, and put together in accordance with a scheme developed by Ault, Novak, and Gowin (1984, 1988). It is idealized in the sense that students are supposed to fully understand the concepts and principles shown in Fig. 2 upon studying the related materials in the textbook. This conceptual structure consisted of the following three major levels.

C-1: Key concepts of the selected topic. These concepts may directly refer to or stand for the events of interest, and are related to one or more statements appearing at the C-2 level.

C-2: A set of principles, in propositional forms, with appropriate link to elements of theory at the C-3 level.

C-3: A phrase or word identifying a relevant theory or its reduced counterpart.

Incidentally, it may be worthwhile pointing out that in the standardized junior-high physical-science textbook heat is defined as a type of energy, and it is stated that the temperature of an object changes as heat flows in or out of the object. Summers (1983) has discussed such problems from textbooks in other countries.

(2) Development of the paper-and-pencil test

A paper-and-pencil test was developed based on the idealized conceptual structure shown in Fig. 2. The purpose of the paper-and-pencil test was to probe

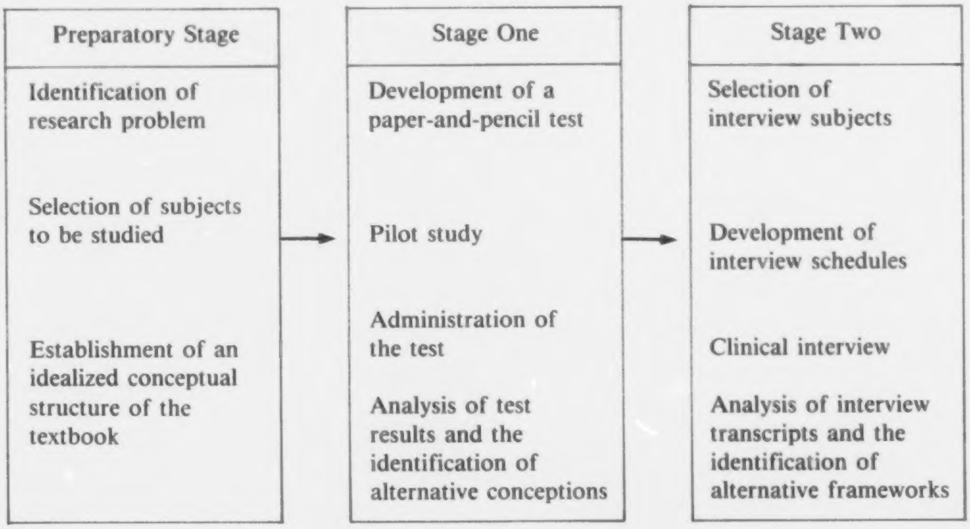

Preparatory Stage
Identification of research problem
Selection of subjects to be studied
Establishment of an idealized conceptual structure of the textbook
Stage One
Development of a paper-and-pencil test
Pilot study
Administration of the test
Analysis of test results and the identification of alternative conceptions
Stage Two
Selection of interview subjects
Development of interview schedules
Clinical interview
Analysis of interview transcripts and the identification of alternative frameworks

Fig. 1. Flow chart for the research procedures

students' understanding of the principles shown at the C-2 level of Fig. 2. Most items were open-ended questions dealing with terms and situations which were familiar to students from their experiences in daily life and science classrooms. The questions were carefully designed, phrased, and pilot-tested to make sure that they were properly understood, and that they were able to elicit students' responses which indicated their conceptions of heat and temperature.

(3) Development of interview schedules

An interview schedule was prepared for selected students. This was based on the student's responses to test items in the paper-and-pencil test which were reviewed in advance. It consisted of questions aimed at identifying the student's alternative conceptions and usage of terms which needed further clarification. These questions dealt with the same problem situations presented in the paper-and-pencil test. In addition, several 3''x5'' cards showing enlarged pictures taken from the paper-and-pencil test were used as aids during the interview.

2. Data collection and analysis

(1) Paper-and-pencil test

The paper-and-pencil test was administered to a sample of 106 students, which consisted of a seventh-grade and an eighth-grade class of a junior high school located in Changhua City. Because students' abilities are supposedly normally distributed according to general educational practice here, the subjects in this study were judged to be representative. Grade-eight students had studied heat and temperature in their physical-science class, while grade-seven students had not.

Students' responses were analyzed for each test item. Responses relevant to this study were classified into appropriate categories, which represented students' alternative conceptions. The formation of such categories was arrived at by a series of steps in which similar responses were grouped together based on their similarities in physical meaning and/or conceptual understanding. A table showing the distribution of students' alternative conceptions was then constructed (not shown here), while keeping track of each students' responses under such scheme of classification. Students' alternative conceptions thus obtained provided an important tool for selecting interview subjects and an intermediate step toward the identification of students' alternative frameworks.

(2) Clinical interview

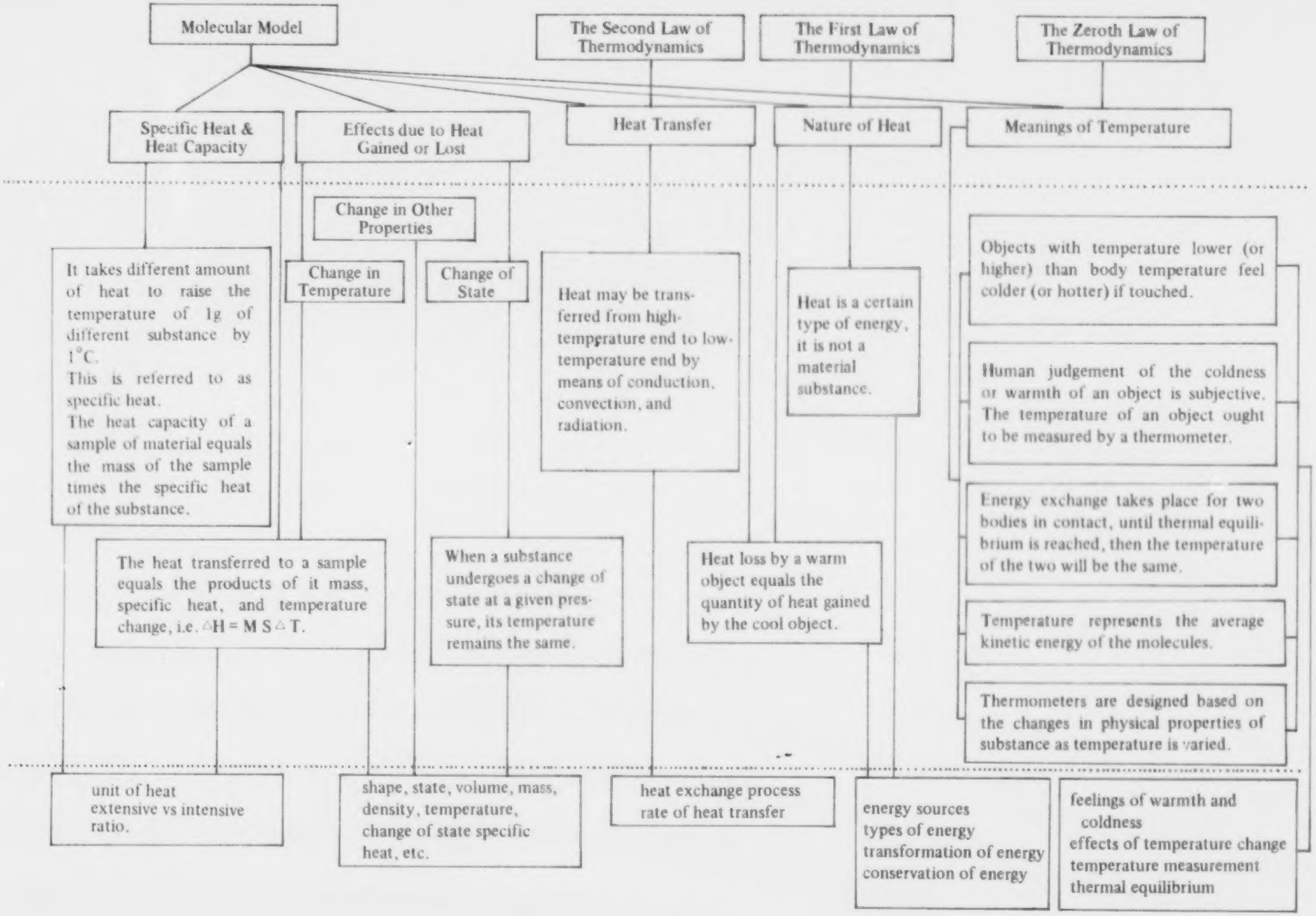
Based on the distribution of students' alternative conceptions obtained from analyzing results of the paper-and-pencil test, a total of twelve students, including equal numbers of seventh and eighth graders, were selected for interview. The criteria for the selection of interview subjects were:

A. At least two students pertaining to each alternative conception were chosen for interview.
B. Students having more alternative conceptions as revealed by their responses to different test items were chosen with higher priority than those having only very few alternative conceptions.
C. Students giving more detailed answers were preferred to those giving only very brief description or explanation.

The techniques for carrying out the interview followed Piaget's clinical interview method, which had been described in great detail by Pines, Novak, Posner, and van Kirk (1978). However, certain features from techniques developed by other researchers (Osborne and Freyberg, 1985; Gilbert, Watts, and Osborne, 1985) were also exploited. The techniques of interview-V developed by Novak and Gowin (1984), and Ault, Novak, and Gowin (1984, 1988), were found to be particularly useful for the analysis, synthesis, and interpretation of the data obtained from interview. The procedures suggested by the techniques of interview-V were closely followed in this study. Students' alternative conceptions were inferred from a systematic procedure in which students' statements taken from the transcripts of audio tapes recorded during the interview were reduced to a form that was to be compared with the C-2 level principles in Fig. 2.

(3) Establishing students' alternative framework

The results of students' alternative conceptions obtained from both the paper-and-pencil test and the interview were combined and reorganized into a more comprehensive list of students' alternative conceptions on heat and temperature. It was at this stage that the focus of the study of students' conceptions started to shift from concerns about each individual student toward identifying physically meaningful patterns of thought which were shared by many students. A further inference was made in order to identify the alternative frameworks which were judged to be the underlying belief systems capable of explaining the occurrence of the listed alternative conceptions in a logical and meaningful way. Usually, an alternative framework was superordinate to a number of alternative concep-


Molecular Model
The Second Law of Thermodynamics
The First Law of Thermodynamics
The Zeroth Law of Thermodynamics
Specific Heat & Heat Capacity
Effects due to Heat Gained or Lost
Heat Transfer
Nature of Heat
Meanings of Temperature
Change in Other Properties
Change in Temperature
Change of State

It takes different amount of heat to raise the temperature of 1g of different substance by 1°C. This is referred to as specific heat. The heat capacity of a sample of material equals the mass of the sample times the specific heat of the substance.

Heat may be transferred from high-temperature end to low-temperature end by means of conduction, convection, and radiation.

Heat is a certain type of energy, it is not a material substance.

Objects with temperature lower (or higher) than body temperature feel colder (or hotter) if touched.

Human judgement of the coldness or warmth of an object is subjective. The temperature of an object ought to be measured by a thermometer.

Energy exchange takes place for two bodies in contact, until thermal equilibrium is reached, then the temperature of the two will be the same.

Temperature represents the average kinetic energy of the molecules.

Thermometers are designed based on the changes in physical properties of substance as temperature is varied.

The heat transferred to a sample equals the products of it mass, specific heat, and temperature change, i.e. $\Delta H = M S \Delta T$.

When a substance undergoes a change of state at a given pressure, its temperature remains the same.

Heat loss by a warm object equals the quantity of heat gained by the cool object.

unit of heat
extensive vs intensive
ratio.

shape, state, volume, mass, density, temperature, change of state specific heat, etc.

heat exchange process
rate of heat transfer

energy sources
types of energy
transformation of energy
conservation of energy

feelings of warmth and coldness
effects of temperature change
temperature measurement
thermal equilibrium

Fig. 2. An idealized conceptual structure of heat and temperature

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tions, in very much the same way as a C-3 label is related to several C-2 principles shown in Fig. 2.

III. Result

Because of space limitation, it is impossible to include examples of students responses to the questions asked in the written test and during the clinical interview. Original data obtained from the twelve subjects interviewed, as well as results obtained from a detailed analysis of students' responses to the written test, may be found elsewhere (Guo, 1990b). Since it is the aim of this study to find students' alternative frameworks of heat and temperature, it is important to first present students' alternative conceptions of heat and temperature. Results for students' alternative frameworks will be shown subsequently.

1. Students' alternative conceptions of heat and temperature

A list of students' alternative conception so obtained from combined findings of both the paper-and-pencil test and the interview is given below.

A. Conceptions of temperature
a. Temperature of an object considered as its intrinsic property, with the effects of environment neglected. For instance, metal is cold, wood is neither hot nor cold, and the temperature of an ice cube is thought to be lower than 0°C, even though it is melting slowly in ice water.
b. Temperature and heat were not differentiated. Heat and temperature were both considered to represent the "hotness" of an object. Heat and temperature were referred to as the same quantity. Temperature was considered as an extensive quantity, heat as an intensive quantity.

B. The nature of heat and heat transfer
a. Heat was a sort of gas, like water vapor or smoke, which consisted of hot and cold gases.
b. Heat was a kind of force or energy, which was produced by temperature.
c. Matter conducted heat by means of diffusion of temperature, heat, or molecules.
d. Glass was capable of conducting heat because there were tiny holes allowing temperature, heat, hot gases, hot molecules and so on to slip in, and cold molecules to slip out.
e. Heat was confused with temperature. For instance, temperature was transmitted from the higher-temperature to the lower-temperature end, and heat was transferred from an object having more heat to one having less.

C. Effects due to the absorption and the release of heat
a. The temperature of an object increased with continued heating, even during phase transition.
b. An egg cooked in boiling water stopped taking in further heat when well-done, resulting in a temperature difference between egg and hot water.
c. Heat absorbed by water was stored within the "density" of water (meaning, the thin space in between the molecules).
d. As boiling water was kept heated, water temperature remained at 100°C and the absorbed heat would "diffuse" into air, leaving molecules in the water unaffected.

D. Specific heat and heat capacity
a. A lack of the concept of specific heat. The heat absorbed or released by an object was considered to be influenced by factors including mass and temperature change only.
b. Confusion of heat capacity and temperature, taking the heat capacities equal for two objects having the same temperature.
c. Lacking the concept of heat capacity. The rates of heat dissipation and heat transfer were used in its stead in explaining related phenomena.

2. Students' alternative frameworks on heat and temperature

As mentioned previously, an alternative framework is a pattern of thought related to a specific science topic at a higher level of abstraction and unification. It is an inferred model capable of explaining the occurrence of a number of students' alternative conceptions. With the full awareness that an effort in identifying students' alternative frameworks involves unavoidable subjective judgement and a high level of inference, the author suggested the occurrence of the following alternative frameworks in an attempt to summarize students' alternative conceptions listed above.
A. Overlooking or lacking the concept of thermal equilibrium (A-a, A-b, C-b).
B. Heat and temperature are the same, proportional, or causally related to each other (A-c, B-b, B-e, C-a, D-a, D-b, D-c).
C. Heat, like gases, consists of material substance (B-a, B-c, B-d, C-c).
D. Passive roles of molecules when an object was heated (C-d).

The labels enclosed in the parentheses above indicate the corresponding students' alternative conceptions which are subsumed under each alternative framework.

IV. Discussions

Before discussing the significance of the research findings, it must be pointed out that in focusing on the investigation and description of students' alternative conceptions and alternative frameworks, we have left out other important results showing how students used reasonings based on their daily experiences and the knowledge they learned from formal instruction to offer acceptable explanations and solutions to questions asked in this study. Some rough ideas about this may be obtained by noting that for the eighth-grade subjects in this study typically 50% to 80% of the students gave acceptable answers to each test item in the written test, and for each alternate conception listed in Section III, typically 5% to 20% of the eighth-grade subjects were found to hold such an alternative conception (Guo, 1990b). The performances of the seventh-grade subjects, who had not yet received any formal instruction in physical science at the junior-high-school level, were generally worse by a factor of two, approximately. Obviously, science instruction at schools is successful to some extent, but the occurrence and persistence of students' alternative conceptions are noteworthy, especially in view of the far-reaching educational implications they engender (Osborne and Wittrock, 1985; Linn, 1987; Driver, 1989).

Based on a detailed discussion of related studies reviewed elsewhere (Guo, 1990b), it is noteworthy that most of the results obtained in this study of students' alternative conceptions of heat and temperature had been reported for students of a wide age range in other countries. The few exceptions are B-c, C-c, and C-d, which seem to arise from a misunderstanding of the terms density and diffusion.

In addition to paving the way for further researches concerning the study of students' alternative frameworks in science and their instructional implications, the significance of this study lies in exploring the efficiency and versatility of its research methods. The researcher kept in mind that there were certain factors and procedures that ought to be taken into account in order to establish the internal validity of interpretive or qualitative research (Erickson, 1986; Lythcott and Duschl, 1990). Various steps were taken to make sure that the findings would correspond to students' conceptions rather than mere artifacts of the researcher's bias in framing the questions and/or in data analysis and synthesis. As mentioned previously, the combined use of the paper-and-pencil test and the interview was very helpful in selecting the interview subjects and in identifying students' alternative conceptions. It provided a way to cross-check students responses and the researcher's interpretations.

The use of students' responses from a paper-and-pencil test as a reference for designing an interview schedule added another advantage, because it provided not only a tentative conceptual framework of the student to be further examined and confirmed by interview, but also a list of terms and words from which the researcher was able to build upon the conversation after certain clarification. Many students interviewed in this study indicated that they were able to think more carefully and systematically in writing rather than in talking. Referring to what they had written turned out to be a useful way to help students concentrate on formulating an explanation, and to encourage them to talk. However, lest the written responses become too restrictive, the researcher often stopped during the interview and encouraged students to provide additional opinions or modifications which they thought were appropriate.

Returning to the alternative conceptions listed in Section III, it is interesting to note that qualitatively similar alternative conceptions on heat and temperature had been found from studies carried out elswhere, for instance, Erickson (1979), Driver and Russel (1982), Appleton (1984), Brook, Biggs, Bell, and Driver (1984), Hollon and Anderson (1986), Wiser and Kipman (1988). This lends strong support to the occurrence of commonly shared alternative conceptions in science, indicating that the idea of introducing alternative frameworks into research in science education is justifiable.

Just as it was reported in the literature, the researcher noted in this study that there were a few cases in which students' responses to similar tasks with different problem contexts were different or inconsistent with each other. This often leads critics to doubt the existence of an alternative framework as a stable and consistent set of concepts and rules which students use to interpret the world around them. There are, however, possible explanations from a constructivist point of view. For instance, student interpretation and conception of the problems may be very different from those of the researcher. What was considered as the same concept and/or principle by the researcher might have been overlooked or blocked out by other distracting factors. What the researcher deemed inconsistent might not cause any sense of concern in the students, because of certain features of their cognitive structure. Another possibility is to interpret students' conceptual knowledge as consisting of central (hard-core) and peripheral (protective belt) ideas, the former being very stable and resistant to change while the latter is more susceptible to change (Linn, 1986; Heller and Finly, 1992). Of course, it appears that further studies are required in order to clarify this point.

V. Conclusions

The study of students' learning and conceptions in science, especially from the constructivist perspective, has received worldwide attention in recent years. An attempt was made in this work to identify the alternative frameworks on heat and temperature for junior-high-school students in Taiwan. The interview subjects included six seventh-grade students and an equal number of eighth-grade students. They were purposely chosen from two classes of a nearby school, involving 106 students whose alternative conceptions were studied in advance using a written test developed in this study. The nature of this study was both descriptive and exploratory, yet it provided a good starting point for conducting further research activities along the same lines. In fact, similar investigations of students' alternative frameworks on motion, force, energy, and sound have been carried out by the author and a number of graduate students under his supervision. Other research efforts, including the development of diagnostic paper-and-pencil tests for identifying students' alternative conceptions and frameworks in optics and chemical reactions, as well as the development of teaching strategies which will facilitate students' conceptual change in science, either have been completed recently or are still under way in this institute. Apparently, the study of students' conceptions in science is an interesting and promising field which invites continuing concentrated research efforts at both basic and applied levels.

References

Abimbola, I.O. (1988). The problem of terminology in the study of student conceptions in science. *Science Education, 72*(2), 175-184.

Appleton, K. (1984). *Children's ideas about hot and cold.* Learning in Science Project. Working Paper No: 127. ERIC Document No: ED 252 407.

Ault, C.R., Novak, J.D., & Gowin, D.B. (1988). Constructing Vee maps for clinical interview on energy concepts. *Science Education, 72*(4), 515-545.

Ault, C.R., Novak, J.D., & Gowin, D.B. (1984). Constructing Vee maps for clinical interview on molecule concepts. *Science Education, 68*(4), 414-462.

Bodner, G.M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63*(10), 873-878.

Brook, A., Briggs, H., Bell, B., & Driver, R. (1984). *Aspects of secondary students' understanding of heat.* Children's Learning in Science Project. Centre for Studies in Science and Mathematics Education. University of Leeds.

Cleminson, A. (1990). Establishing an epistemological base for science teaching in the light of contemporary notions of the nature of science and of how children learn science. *Journal of Research in Science Teaching, 27*(5), 429-445.

Driver, R. (1989). Students' conceptions and the learning of science. *Int. J. Sci. Educ., 11,* Special Issue, 481-490.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5,* 61-84.

Driver, R., & Erickson, G. (1983). Theories in action: Some theoretical and empirical issues in the study of students conceptual frameworks in science. *Studies in Science Education, 10,* 37-60.

Driver, R., & Russell, T. (1982). *An investigation of ideas of heat, temperature, and change of states of children aged between 8 and 14 years.* University of Leeds and Chelsea College, London.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: A constructivist view. *School Science Review, 67,* 443-456.

Driver, R. (1981). Pupils' alternative frameworks in science. *Eur. J. Sci. Educ., 3*(1), 93-101.

Duschl, R. (1990). *Restructuring science education: The role of theories and their importance.* New York: Teachers College Press.

Erickson, F. (1986). Qualitative methods in research in teaching. In M.C. Wittrock (ed.), *Handbook of research on teaching* (3rd ed., 119-161). New York: Macmillan.

Erickson, G. (1979). Children's conceptions of heat and temperature. *Science Education, 63*(2), 221-230.

Gauld, C. (1987). Student beliefs and cognitive structure. *Research in Science Education, 17,* 87-93.

Gilbert, J.K., Watts, D.M., & Osborne, R.J. (1985). Eliciting student views using an interview-about-instance technique. In West, L.H.T. and Pines (eds.), *Cognitive structure and conceptual change.* New York: Academic Press.

Gilbert, J.K., & Watts, D.M. (1983). Concepts, misconceptions and alternative conceptions: Changing perspectives in science education. *Studies in Science Education, 10,* 61-98.

Guo, C.J. (1988). On learning science: A review of research from cognitive perspectives. *Journal of National Taiwan College of Education, 13,* 351-379 (in Chinese).

Guo, C.J. (1990a). On the assessment and description of students' cognitive structures about scientific knowledge. *Journal of National Changhua University of Education, 1,* 279-320 (in Chinese).

Guo, C.J. (1990b). *On the use of clinical interview to probe students' alternative frameworks toward important physics concepts* (II). Report to National Science Council (in Chinese).

Head, J. (1986). Research into "alternative frameworks": Promise and problems. *Research in Science and*

Technological Education, 4(2), 203-211.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. *Science Educaiton, 72,* 19-40.

Hollon, R.E., & Anderson, C.W. (1986). *Heat and temperature: A teaching module.* Occasional paper No: 93. ERIC Document No: ED 273 453.

Linn, M.C. (1987). Establishing a research base for science education: Challenges, trends, and recommendations. *Journal of Research in Science Teaching, 24*(3), 191-216.

Lythcott, J. & Duschl, R. (1990). Qualitative research: From methods to conclusions. *Science Education, 74*(4), 455-460.

Marton, F. (1981). Phenomenography — Describing conceptions of the world around us. *Instructional Science, 10,* 177-200.

Novak, J.D. (1988). Learning science and the science of learning. *Studies in Science Education, 15,* 77-101.

Novak, J.D., & Gowin, D.B. (1984). *Learning how to learn.* New York: Cambridge University Press.

Osborne, R., & Freyberg, P. (Eds.) (1985). *Learning in science: The implications of children's science.* London: Heinemann Press.

Osborne, R., & Wittock, M. (1985). The generative learning model and its implications for science education. *Studies in Science Educaiton, 12,* 59-87.

Piaget, J. (1971). *Biology and knowledge.* Edinburgh University Press.

Pines, A.L., Novak, J.D., Posner, G.J., & Van Kirk, J. (1978). *The clinical interview: A method for evaluating cognitive structure.* Research Report No. 6. Ithaca, New York: Department of Education, Cornell University.

Summers, M.K. (1983). Teaching heat — an analysis of misconceptions. *School Science Review, 64*(229), 670-675.

Tobin, K.G. (1991). Learning from interpretive research in science classrooms. In J.J. Gallagher (ed.), *Interpretive research in science education.* The National Association for Research in Science Teaching, 197-216.

Wheatley, G.H. (1991). Constructivist perspectives on science and mathematics learning. *Science Education, 75*(1), 9-21.

White, R.T. (1988). *Learning science.* New York. Basil Blackwell Inc.

Wiser, M., & Kipman, D. (1988). *The differentiation of heat and temperature: An evaluation of the effect of microcomputer models on student's misconceptions.* ERIC Document No: ED 303 367.

Wittrock, M.C. (1986). Student's thought processes. In M.C. Wittrock (ed.), *Handbook of research on teaching* (3rd ed., 297-314). New York: Macmillan.

國中學生熱與溫度的另有架構

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摘　要

本文旨在探討國中一、二年級學生對熱與溫度的另有架構，國二學生在國中理化課程中曾學過相關的題材，國一學生則尚未教到。所謂另有架構係指和學科內容有關的一個基本的、闡釋性的模型，它能說明由許多學生所共同持有的一些另有想法。在本研究中採用紙筆測驗和臨床晤談的二段式研究設計，藉以找出學生在熱和溫度方面的另有想法，亦即學生所另行持有的一些不符一般科學說明的想法。晤談對象包括國一、國二學生各六位。他們係以立意方式自兩班共106位學生中選出，這些學生事先曾接受紙筆測驗，而其對熱與溫度的另有想法已由分析紙筆測驗結果予以確認。晤談所得數據的化簡、分析、和綜合係根據Ault, Novak，和Gowin所發展的晤談V圖的技術。由紙筆測驗晤談所找出學生對熱與溫度的另有想法經相互驗證後予以合併。審視學生這些另有想法的本質及其物理意義，在本研究中獲致下列另有架構：

1. 缺乏熱平衡概念。
2. 熱與溫度的混淆。
3. 視熱爲實體存在的物質。
4. 加熱時物體內的分子不受影響。

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Correlation of Achievements in Extraction Technique with Science-Process Skills and Subject-Matter Knowledge

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ABSTRACT

This paper presents a method for effective instruction and mastery learning of the extraction technique at the university level. We developed instructional materials and strategies to help students achieve the three successively higher levels of performance — concrete, identity, and classificatory. Mastery learning of chemistry experimental techniques is quite demanding and expected to evoke the students' ability to apply simultaneously proficiency in laboratory technique, intellectual-inquiry skills, and functional knowledge of subject matter. The positive correlations among (a) science-process skills, (b) subject-matter knowledge, and (c) student achievements in chemistry experiments supported the expectation. The results proved that the mastery learning model synthesized by us was effective in promoting learning of higher levels for the extraction technique.

Key words: mastery learning, chemistry laboratory technique, effective instruction, extraction, relationships among experimental skills, science-process skills, subject-matter knowledge

I. Introduction

Although practical work has always been given great emphasis, many students have failed to develop basic practical skills (Tamir, 1989). Usually a laboratory course adopts experiments mainly from a textbook without due consideration of instructional strategies. Students' techniques are assessed on the basis of impression grading, which fails to identify students' shortcomings and to give remedial instruction. Some students might be able to perform as instructed, but their temporary, superficial proficiency in the technique fades away quickly. After a couple of years these students would join in research programs to find themselves badly in need of regaining many of the basic laboratory techniques. Effective teaching of any single technique can not be achieved without instructional strategies including selecting sequence assignments and assessing how well the students have performed the technique in how many diversified situations. Students trained by such effective teaching can then achieve transfer of learning and are ready to deal successfully with new chemical problems (Wang and Horng, 1991).

According to Johnstone and Wham (1982) the inquiry-oriented laboratory investigations require that the students simultaneously apply the functional knowledge of subject-matter, proficiency in laboratory techniques (e. g., use of a microscope), and intellectual-inquiry skills (e.g., formulating hypotheses). Woolnough and Allsop (1985) observed that intellectual skills fail to develop because practical laboratory work does not focus on the development of basic process skills. Another reason for this failure is the absence or inadequacy of pre-laboratory discussion, which is essential for relating the laboratory activities to science-process skills and relevant concepts (Friedler and Tamir, 1986; Tamir, 1977; Woolnough and Allsop, 1985). Novak and Gowin (1984) have invented concept mapping and Vee diagramming, which help associate concepts and knowledge with laboratory experience. Extraction, one of the chemistry experimental techniques, is a multiple task having critical attributes and belongs to the class of "process concepts" (Herron *et al.*, 1977). A multiple task has a number of possible inputs. The task is performed according to the input. By only one assignment the students can merely acquire the initial learning. Students must do a rational set of successive follow-up assignments to master a concept (Klausmeier, 1980; Dumas Carré and Larcher, 1987). Mastery learning of chemistry experimental techniques is quite a demanding task and is expected to evoke, in its process, the students' ability to simultaneously apply proficiency in the laboratory techniques, intellectual inquiry skills, and functional knowledge of the subject matter. Students must make a conscious effort to relate knowledge already obtained in the typical case to the new experimental contexts. If this is the case, we expect to obtain positive correlations among proficiency in experimental techniques, science-process skills, and subject-matter knowledge.

The purposes of this study are (1) to develop the instructional materials, assessment tools, and instruction/assessing strategies for mastery learning of extraction using our mastery learning model previously described (Wang and Horng, 1991), (2) to determine the effectiveness of our model, and (3) to determine the degrees of relationships of the laboratory-technique proficiency with the test achievements in the unit laboratory skills, in the science-process skills, and in the subject-matter knowledge. Laboratory skills are defined here as the parts skills of the laboratory technique to be learned.

II. Methods

The subjects for this study were 23 sophomores in the Department of Chemistry, National Taiwan Normal University. The method and procedure of our own design (Wang and Horng, 1991) were used to develop instructional materials, assessment instruments, and instruction/assessment strategies. The recitation class was held to conduct adequate pre-laboratory discussion, which is essential to relate the laboratory activities to the science-process skills and subject-matter knowledge. The pre-test preceded the recitation class which was to find out what the students already knew. Right after the recitation, post-test 1 was given. A first assignment, a second assignment, then a rational set of activities were given followed by post-test 2 to find out whether the students had understood concepts from the instruction. The tests were of true/false type. A classroom information system with a response analyzer was developed to provide the instructor with information on class progress and individual student's responses. The Classroom Information System (CIS) consists of a large-screen display, a teacher's host computer with a monitor, the S-P chart analysis system, student input units, an overhead projector, some interface equipment, etc. The CIS can: (1) Collect and record each student's response data. (2) Analyze the response data. (3) Provide the instructor with information for decision making. (4) Provide students with instant feedback information for self-confirmation, self-reinforcement, self-correction, and group learning, which lead to self-generated motivation and attention.

The three successively higher learning levels, i.e., concrete, identity, and classificatory, were described previously (Wang and Horng, 1991). In this study they were treated as follows. At the concrete level, students were closely guided with programmed instruction to gain declarative knowledge ("knowing that") and procedural knowledge ("knowing how") in a typical case before they performed the experiment. At the identity level, students worked on a similar experiment related to the case of the concrete level using its reasonings as a guide to find out what to do. At the classificatory level, students were challenged with a set of representative cases and unknown cases; they had to use subject-matter knowledge and science-process skills to find ways and means to solve the problems.

III. Results and Discussion

1. Mastery learning of extraction technique

(1) The concrete level

Students at this level should be able to correctly perform the technique on a typical sample and have the ability of "recognition-repetition", with which to recognize that the specific situation has been studied and to repeat the procedure as instructed. In the case of the extraction technique, the student should be able to correctly extract mandelic acid from aqueous solution with ether, a typical example. Whether the students had really attained the concrete level of learning was first evaluated by the test items that could evaluate the students' ability to perform correctly. Item-response tables and S-P charts (Chart 1, 2, 3) were constructed from the results of these tests and analyzed.

(2) The identity level

The ability at this level is "identification-reproduction", with which the student can reproduce

Chart 1. S-P Chart for Extraction — Concrete Level
Pre-test

PROBLEM NUMBER $D^* = 0.5479$ Average P_j = 74%

STUDENT NO.	01	07	03	10	12	11	09	04	05	14	15	06	02	08	13	16	C.A.	%	CS_i
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	14	87	0.00
9	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	14	87	0.19
23	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	14	87	0.39
11	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	14	87	0.52
4	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1	13	81	0.34
10	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	13	81	0.34
7	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	13	81	0.39
15	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	13	81	0.44
13	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	13	81	0.58
6	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	13	81	0.63
8	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	13	81	0.63
18	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	13	81	0.63
12	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	12	75	0.20
20	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	0	12	75	0.20
3	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	11	68	0.10
21	1	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	11	68	0.43
14	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	0	11	68	0.61
5	1	1	1	1	1	0	1	1	1	0	1	1	0	0	0	0	10	62	0.23
22	1	1	1	1	1	0	1	0	0	1	1	0	0	1	0	0	9	56	0.38
1	1	1	1	0	1	1	0	1	0	1	0	1	0	1	0	0	9	56	0.48
16	1	1	1	1	0	1	0	1	0	0	0	0	1	0	0	0	7	43	0.26
2	1	1	0	1	1	1	0	1	0	0	0	0	1	0	0	0	7	43	0.29
C.A.	23	23	22	22	21	20	19	19	16	16	15	14	13	12	10	09			
P_j, %	100	100	95	95	91	86	82	82	69	69	65	60	56	52	43	39			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CP_j	.00	.00	.00	.40	.40	.54	.25	.89	.30	.56	.49	.39	.84	.78	.23	.31			

C.A.: Number of correct answer
"——": S-curve; "-----": P-curve

for a comparable case the procedures performed at the concrete level. For the technique, the student can successfully perform extraction of caffeine from aqueous solution with dichloromethane, which case is comparable to that at the concrete level. The test items used here could evaluate the students' ability in making comparative analysis of the new case against the task performed at the concrete level.

(3) The classificatory level

The ability of a student at this level is "generalization to all ordinary cases". For the extraction technique, the student can successfully perform on a rational set of ordinary mixtures, such as extraction of p-chlorotoluene from aqueous solution with ether, extraction of aniline from aqueous solution with dichloromethane, and acid-base extraction from an organic solution. The task includes successfully separating an unknown mixture, including selecting an appropriate solvent. The test items used here could evaluate the students' ability in making generalizations from various attributes of assignments and in giving accurate judgments on new situations.

The efficiency of instruction was evaluated by the degree of learning progress. The latter was evaluated with positive correlations between two consecutive tests, between task performance and test result, and among the results of a set of laboratory assignments. Progress in learning was observed in the rightward shifts of the S-curves and the downward shifts of the P-curves during the set of assignments. Progress in learning was also observed from the average passing rate increments. The average passing rate increased from the pre-test to the post-test 1 to post-test 2: the values for the concrete level are 74%, 88%, and 92%; those for the identity level are 55%, 84%, and 93%; those for the classificatory level are 76%, 94%, and 97%. CP_j values of all items are less than 0.39. In the plots of P_j vs. CP_j, all items

Chart 2. S-P Chart for Extraction — Concrete Level
Post-test 1

PROBLEM NUMBER D* = 0.3811 Average P_j = 88%

STUDENT NO.	01	04	06	07	10	12	03	13	16	11	05	08	09	14	02	15	C.A.	%	CS_i
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
9	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	15	93	0.82
11	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	15	93	0.90
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	14	87	0.00
7	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	14	87	0.12
15	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	14	87	0.12
2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	13	81	0.54
19	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	12	75	0.00
13	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	12	75	0.04
23	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	0	12	75	0.24
8	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1	12	75	0.53
14	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	0	11	68	0.39
22	1	1	1	1	1	1	0	1	1	0	1	0	0	0	0	0	9	56	0.13
C.A.	23	23	23	23	23	23	22	22	22	21	19	18	18	18	16	08			
P_j, %	100	100	100	100	100	100	95	95	95	91	82	78	78	78	69	34			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CP_j	.00	.00	.00	.00	.00	.00	.00	.40	.40	.12	.50	.14	.14	.57	.11	.41			

C.A.: Number of correct answer

"——": S-curve; "- - -": P-curve

were in upper left Quadrant. These facts indicated that all items were of good quality. Acceptably small degree of anomalous item patterns in the S-P chart reflected unambiguous instruction. In each post-test 2 for the three levels, all the CS_i values for individual students were less than 0.39 and all the three D* values were less than 0.3282. Small CS_i and D* values indicated acceptably small degree of learning difficulties and erratic studies (careless mistakes, copying or guessing responses) after the instruction (Sato, 1980). All students passed the experimental assignments at the concrete level and the identity level. Twenty-one students (91%) passed the experimental assignments at the classificatory level. Students were considered to have reached the classificatory level only if they successfully completed 80% or more of the assigned cases and separation of an unknown mixture. Once the students mastered the technique, they kept the ability. These facts were consistent with the learning gain shown in individual performance profiles (Table 1). The progress of learning observed as discussed above indicated the effectiveness of our instructional method for mastery learning of the technique. These instructional materials and strategies were satisfactory for the college introductory organic chemistry laboratory course. These results indicate that the model used is effective.

2. *Relationships of extraction-technique proficiency with science-process skills and subject-matter knowledge*

We think that mastery learning of chemistry experimental techniques may become a device with which students will develop intellectual inquiry skills as they

Chart 3. S-P Chart for Extraction — Concrete Level
Post-test 2

PROBLEM NUMBER D* = 0.2226 Average P_j = 92%

STUDENT NO.	01	03	04	06	07	10	11	12	13	16	08	05	09	14	02	15	C.A.	%	CS_i
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	100	0.00
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	15	93	0.00
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	14	87	0.00
7	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	14	87	0.06
15	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	14	87	0.06
19	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	13	81	0.00
14	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	13	81	0.11
23	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	13	81	0.23
13	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	12	75	0.10
22	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	11	68	0.00
C.A.	23	23	23	23	23	23	23	23	23	23	21	21	20	19	18	09			
P_j, %	100	100	100	100	100	100	100	100	100	100	91	91	86	82	78	39			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
CP_j	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.15	.31	.00	.30	.08	.00			

C.A.: Number of correct answer

"——": S-curve; "---": P-curve

are forming a generalization that is rooted in the typical example already learned. Extraction is a process in which a solute is selectively recovered from a mixture with a solvent. To achieve good experimental results, students should be able to make the correct judgements and choices at the decision steps: (Fig. 1) (a) selecting an extraction solvent and (b) identifying which is the organic layer for the new experimental cases. These abilities are the results of learning transfer. The major science-process skills needed in decision-making steps for extraction are inference and prediction. The subject-matter knowledge needed is solubility and liquid density. Solubility in turn is related to molecular structure, solvent polarity, and salting-out. Generalization-adjunct questions using the classroom information system focus students' attention, accelerating and enhancing conceptualized learning of the experimental technique. We assume good related subject-matter knowledge combined with good science-process skills will accelerate reaching the higher learning levels of the technique. By detecting existing consequence and searching back through the experimental data, we expect to find possible cause-and-effect relationships of student achievement in chemistry experiments with (a) science-process skills and (b) subject-matter knowledge.

The majority of students obtained good experimental results (high yield and high purity) and did well ($P_j > 80\%$) in the subject-matter knowledge test, science-process skill test, and experimental skill test. A few students obtained poor experimental results and did

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Table 1. Assignments and Attainment Level of Individuals in Extraction

St. No.	*Concrete level* I-R	Practical[a] 1st	2nd	*Identity level* I-R	Practical[b] 1st	2nd	*Classificatory level* I-R	Practical[c] 1st	2nd	3rd	Level attained
1	+	+		+	+		+	+			Classificatory
2	+	+		+	+		+	+			Classificatory
3	+	+		+	+		+	+			Classificatory
4	+	+		+	+		+	+			Classificatory
5	+	+		+	+		+	+			Classificatory
6	+	+		+	+		+	+			Classificatory
7	+	+		+	+		+	+			Classificatory
8	+	+		+	+		+	+			Classificatory
9	+	+		+	+		+	+			Classificatory
10	+	+		+	+		+	+			Classificatory
11	+	+		+	+		+	+			Classificatory
12	+	+		+	+		+	+			Classificatory
13	—	+		+	+		+	+			Classificatory
14	+	+		+	+		+	+			Classificatory
15	+	+		+	+		+	+			Classificatory
16	+	+		+	+		+	+			Classificatory
17	+	+		+	+		+	—	+		Classificatory
18	+	+		+	+		+	+			Classificatory
19	+	+		+	+		+	+			Classificatory
20	+	+		+	+		+	+			Classificatory
21	+	+		+	+		+	—	+		Classificatory
22	—	+		+	+		+	+			Classificatory
23	+	+		+	+		+	+			Classificatory

I-R (Post-test 2). "I-R", "+", and "—" stand for "item-response", "pass", and "fail", respectively.

[a] Extraction of mandelic acid from aqueous solution with ether.

[b] Extraction of caffeine from aqueous solution with dichloromethane.

[c] Acid-base extraction from organic solution and separation of an unknown mixture after successfully completing 80% or more of the six assignments.

poorly in the tests. The percentage consistencies among test results of (a) science-process skills, (b) subject-matter knowledge, (c) experimental skills, and (d) experimental results are shown in Table 2. At the concrete level, consistencies of experimental technique performances with (a), (b), and (c) are 91%, 91%, and 91% respectively; at the identity level, 83%, 100%, and 91%, respectively; at the classificatory level, 91%, 91%, and 87%, respectively. These facts reflect strongly positive correlations of the actual results of experimental-technique performances with (a) experimental-skill tests, (b) science-process skills, and (c) the subject-matter knowledge.

There are also strongly positive correlations between process-skills vs. subject-matter knowledge, and experimental skills vs. process skills for all the three levels (Table 2).

IV. Conclusion

We studied effective instruction and mastery learning of the extraction technique at the university level. Instruction materials, assessment instruments, and instruction/assessment strategies were developed and tested on 23 sophomores. The experimental figures show that high levels of correlation of the actual results of experimental-technique performance with (a) experimental-skill tests, (b) science-process skills, and (c) subject-matter knowledge. These results indicate that our mastery learning model is highly effective.

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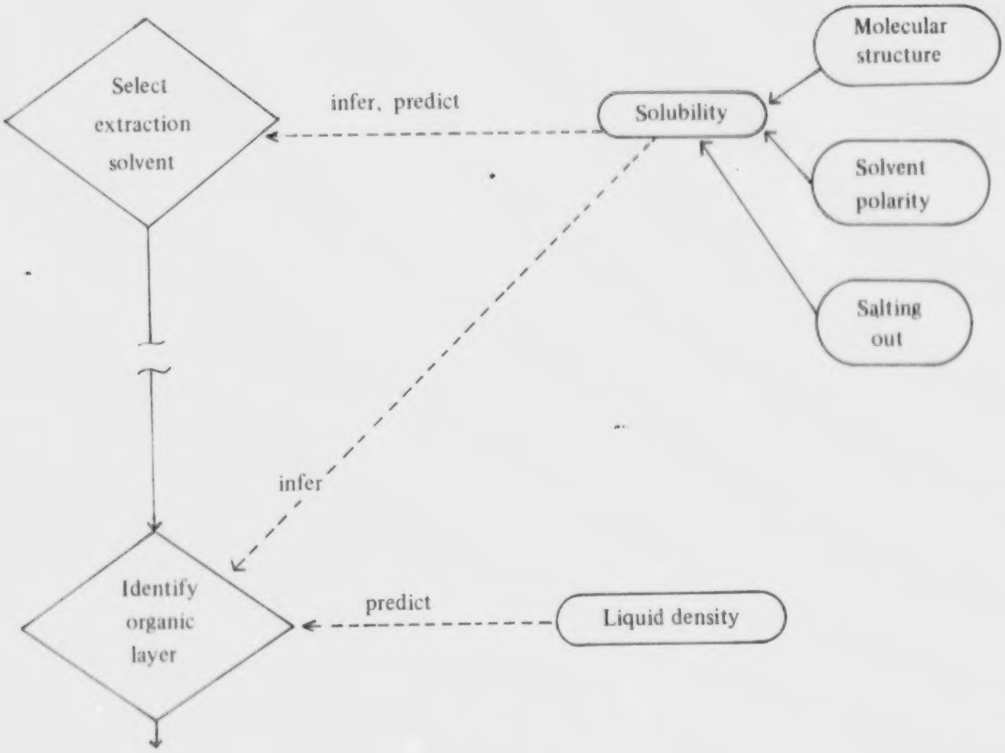
Select extraction solvent
infer, predict
Solubility
Molecular structure
Solvent polarity
Salting out
infer
Identify organic layer
predict
Liquid density

Fig. 1. Correlation among experimental skills, science-process skills, and subject-matter knowledge in extraction

Table 2. Per Cent Consistencies among (a) Science-process Skills, (b) Subject-matter Knowledge, (c) Experimentai Skills, and (d) Experimental Results in Extraction

		Concrete level			Identity level			Classificatory level		
		Science process skills	Expt. skills	Expt. results	Science process skills	Expt. skills	Expt. results	Science process skills	Expt. skills	Expt. results
Subject matter knowledge	Good/Good	87	87	91	83	74	83	100	96	91
	Bad/Bad	0	4	0	0	0	0	0	0	0
	Total	87	91	91	83	74	83	100	96	91
Science process skills	Good/Good		83	91		91	100		96	91
	Bad/Bad		0	0		0	0		0	0
	Total		83	91		91	100		96	91
Expt. skills	Good/Good			91			91			87
	Bad/Bad			0			0			0
	Total			91			91			87

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References

Dumas-Carré, A., & Larcher, C. (1987). The stepping of learning and evaluation. *International Journal of Science Education, 9*(1), 93-104.

Freidler, Y., & Tamir, P. (1986). Teaching basic concepts of scientific research to high school students. *Journal of Biological Education, 20,* 263-270.

Herron, J.D., Cantu, L.L., Ward, R., & Srinivasan, V. (1977). Problem associated with concept analysis. *Science Education, 61*(2), 185-199.

Johnstone, A.H., & Wham, A.J.B. (1982). The demand of practical work. *Education in Chemistry, 19*(3), 71-73.

Klausmeier, H.J., & Sipple, T.S. (1980). *Learning and teaching concepts. A strategy for testing application of theory.* New York: Academic Press, Inc.

Novak, J.D., & Gowin, D.B. (1984). *Learning how to learn.* Cambridge: Cambridge University Press.

Sato, T. (1980). The S-P chart and the caution index. *NEC Educational Information Bulletin 80-1.* C & C System Research Laboratory, Nippon Electric Co., Ltd.

Tamir, P. (1977). How are the laboratory used. *Journal of Research in Science Teaching, 14,* 311-316.

Tamir, P. (1989). Training teachers to teach effectively in the laboratory. *Science Education, 73*(1), 59-69.

Wang, C.H., & Horng, J.M. (1991). A design for implementing mastery learning on sublimation, a chemistry manipulative technique. *Proceedings of the National Science Council, Republic of China, Part D: Mathematics, Science, and Technology Education, 1*(2), 31-41.

Woolnough, B., & Allsop, T. (1985). *Practical work in science.* Cambridge Science Education Series, Cambridge University Press.

萃取實驗技能學習成就與科學過程技能和學科知識之相關研究

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摘　要

本文設計之萃取實驗技能的有效教學與精通學習法，適用於大二有機化學實驗課程。我們發展出的教學資料和教學策略，可使學生達到三個連續提升的學習階層—具體、辨認和歸納階層。化學實驗技能的學習，必須喚起學生的能力，能同時靈活應用實驗技能、科學過程技能和學科知識，來解決新遇到的化學實驗問題。本研究結果顯示，學生的萃取實驗技能學習成就，與科學過程技能及學科知識間有高的正相關。由此可證實此觀點。本研究結果同時證明我們所設計的精通學習模式，能有效的使學生達到較高的三個學習階層。

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Pre-service Elementary School Teachers' Attitudes toward Science Teaching and Their Relationships to Selected Variables

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ABSTRACT

The purpose of this study was to understand pre-service elementary school teachers' attitudes toward science teaching and their relationships with selected variables. Selected variables included basic science knowledge, the number of science courses taken, gender, final grades in: science courses, method course, student teaching; grade point average, science process skills, scientific attitude, and reasoning ability. The 658 graduates of junior teachers' colleges in 1990 were involved. Data was analyzed through frequencies, correlations and multiple regression by SPSSX package. Results indicated that 90% of pre-service teachers agreed with the importance and the nature of science. However, about half of them were afraid of teaching science. Twenty-one percent of the variance in pre-service teachers' attitudes toward science teaching was explained by the selected variables. Scientific attitude, gender, science process skills, and the number of science courses taken were stronger predictors.

Key words: pre-service elementary teacher education, attitudes toward science teaching, scientific attitude, gender, science process skills, science knowledge

I. Introduction

The teacher is the key person to decide actual curriculum in classes. Teachers' attitudes, intended or unintended, will affect students' motivation (Heter, 1985) and learning. Research indicates that teachers who have positive attitudes toward science teaching are more likely to teach science in their classes than those who have negative attitudes toward science teaching (Sherwood and Gabel, 1980; Stefanich and Kelsey, 1989). To help preservice teachers develop positive attitudes toward science teaching should be one of the main concerns in teachers' colleges' science education.

The purpose of this study was to understand preservice elementary school teachers' attitudes toward science teaching and correlations with selected variables in the Republic of China. The selected variables included 1) academic achievement: basic science knowledge, final grades in: science courses, science teaching method course, student teaching; grade point average (GPA); 2) science background: the number of science courses taken; 3) gender; 4) science process skills; 5) reasoning ability; and 6) scientific attitudes.

II. Review of Related Literature

Both Weiss (1978) and Stake and Easley (1978) reported that science teaching was least in priority in elementary school classes. Teachers felt uncomfortable and were reluctant to teach science in elementary schools in the United States. Since the educational system is

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centralized in the Republic of China, elementary school teachers have to teach science as required in the curriculum. However, research also indicates that they are afraid to teach science (Lee, 1982; Chen *et al.*, 1987).

There are many studies related to elementary school teachers' attitudes toward science teaching. Haury (1989) revealed that 'science locus of control orientation' explained 46% of the variance in teachers' attitudes toward science teaching. However, main attributers to 'science locus of control orientation' remained undefined. The relationships among variables which contribute to teachers' attitudes toward science teaching are not clear. Several variables such as teachers' basic science knowledge, final grades of science courses, the number of science courses taken, gender,... etc. are reviewed and summarized in the following.

1. Science knowledge

Blosser and Howe (1969) showed that elementary school teachers' reluctance to teach science was mainly due to their insufficient science knowledge. Lack of science knowledge is always accompanied by much anxiety about teaching science (Westerback *et al.*, 1985). The more anxiety the teachers had, the more negative were their attitudes toward science teaching (Westerback, 1982).

Grossman *et al.* (1989) reported that when teachers were unfamiliar with the subject, they would avoid teaching it, or only teach from textbooks. Grossman (1989) stated that teachers who had stronger subject knowledge would teach the essence and the structure of subjects, which were the most important parts for students to learn.

When the teacher felt comfortable with science content and had confidence in science teaching, he/she would spend more time teaching science and could teach creatively and diversely (Earl and Winkeljohn, 1977; Westerback and Long, 1990).

Teachers' subject matter ability also affects their teaching strategies and skills. Anderson and Druva (1983) indicated that teachers who had stronger science background would ask more complicated and higher thinking level questions. Dobey and Schafer (1984) stated that teachers with stronger science background would be more confident and self-assured when they taught science. Teachers with insufficient science knowledge would more often use a teacher-centered mode and limit both teaching and students' inquiries to their understanding of science to avoid questions which they could not answer. They had no confidence in inquiry teaching.

The relationship between science knowledge and attitudes toward science teaching was well explained by Rubin. Rubin stated that "a teacher's willingness to teach a topic is inseparable from attitude toward the subject; and attitude, in turn, is related to the teacher's competency in the subject area" (Piper and Moore, 1977: 87).

2. Number of science courses taken

Findings on the relationships between the number of science courses taken and teachers' attitudes toward science teaching were not consistent. Gabel (1981) reported that science majors had more positive attitudes toward science and science teaching than non-science majors, and the number of science courses taken did affect student's attitudes toward science teaching. Anderson and Druva's (1983) meta-analysis revealed the same results. However, other investigators reported that there was no relationship between the number of science courses taken and teachers' attitude toward science teaching (Ginns and Foster, 1983; Stepans and McCormack, 1985).

3. Course difference

The correlations of science subjects with pre-service elementary teachers' attitudes toward science teaching were not consistent. Westerback (1982) stated that earth science and biology had positive effects while physics had no effect on teachers' attitudes toward science teaching. On the contrary, Piper and Moore (1977) showed that a physics group had more favorable attitudes toward science teaching than a non-physics group.

4. Method course

Field experiences did not significantly change teachers' commitments to science, but did change their attitudes toward their education and science coursework (Knight, 1975). Research results indicated that competency-based and field-oriented teaching method courses had positive correlation with preservice teachers' attitudes toward hands-on science activities (Piper and Moore, 1977; DeBruin, 1977; Taiwo, 1980).

If science teaching method courses could provide laboratory and peer-teaching experience, it would help pre-service teachers to develop positive attitudes toward science teaching (Pedersen and McCurdy, 1990).

5. Teacher's gender difference

Taiwo (1980) showed that teachers' gender had a greater effect on their attitudes toward science teaching than early field experience. Males had more positive attitudes than females (Taiwo, 1980; Fraser-Abder and Shrigley, 1980). The same result was found in the

Republic of China (Lee, 1990).

6. Science process skills

Activity-oriented or future teaching curriculum-oriented science courses had positive effects on students' attitudes toward science teaching (Gabel and Rubba, 1977; Lucas and Dooley, 1982; Lulz and Orlich, 1988; Atwood and Howard, 1989; Reed *et al.*, 1989). A teacher who had experience in hands-on activity would be more confident and would choose hands-on activities when he/she taught science (Reed *et al.*, 1989). A teacher who had a preference for science process skills would arrange more science process skills in his/her classes (Jaus, 1977). However, Riley (1975) had different findings. He stated that science process training had no significant correlation with pre-service teachers' attitudes toward science teaching.

7. Scientific attitude

Kramer (1976) stated that teachers with negative attitudes toward science would easily object to curriculum change and probably use traditional methods to teach science. Teachers, who had negative attitudes toward science, would also pass this attitude on to their students (Shrigley, 1974). However, Koballa (1986) reported differently. He stated that the evaluation of pre-service teachers' scientific attitudes could not predict teachers' behavior in their science classes.

8. Reasoning ability

It was found that reasoning ability had significantly correlation with science process skills in the last year's study (Lee, 1990). Several studies reveal that science process skills correlate positively with teachers' attitudes toward science teaching. Reasoning ability was selected to understand the relationship between pre-service teachers' reasoning ability and their attitude toward science teaching.

III. Methodology

1. Sample

This paper is part of the results of a longitudinal study. Students (N = 658) who had answered GALT (Roadrangka *et al.*, 1983), TIPSII (Okey *et al.*, 1982), and Scientific Attitude Scale (Moore and Sutman, 1970) in 1988 and graduated from junior teachers' colleges in 1990 participated. Since some students forgot to write down their identification number, part of the current data could not be matched with the previous GALT, TIPSII and Scientific Attitude Scale results and was dropped in regression analysis. Therefore, the sample size of this study varies among the tables.

According to the number of science courses taken, pre-service teachers were categorized as 1) science and mathematics majors; 2) literature and social studies majors; and 3) music, arts and physical education majors who had "general science" only.

2. Instruments

A Chinese version of "Revised Science Attitude Scale" (Thompson and Shrigley, 1986) was used to understand students' attitudes toward science teaching. The last question of the Science Attitude Scale did not fit into Chinese schools. It was dropped from the Chinese version. The scale had been modified and tested twice. The reliability (α) was .84.

Two criterion-referenced science tests which were developed by the author, graduate students, and colleagues were given to students to test their understanding of basic science knowledge. One of the tests included physics and earth science; the other covered biology and chemistry. All items in the tests were related to concepts which were covered in the elementary school science curriculum. Science tests had been judged by experts and modified until the experts agreed. The test reliabilities had been examined by the McNemear-test. The results were not significant, which meant that the science tests were reliable.

Two tests were randomly assigned to classes.

3. Data collection

The Scientific Attitude Scale and science test were given to pre-service teachers, when they finished student teaching, by the author or professors in each teachers' college.

Final grades in: science courses, the science teaching method course, student teaching; grade point average, the number of science courses taken, and gender were provided by teachers' colleges.

Science process skills, scientific attitude, and reasoning ability data were collected in 1988 and computer-merged with new data by identification number.

4. Data analysis

Data were analyzed for frequencies, correlations, and stepwise multiple regression through SPSSX package.

IV. Results

Concerning the ease of teaching science, findings (Table 1) indicated that over 90% of pre-service teachers hoped that they could excite their students about science (item 19) and 44% of pre-service teachers believed that they could teach science well (item 3). However, 31% of pre-service teachers felt uncomfortable teaching science (item 1); 26% dreaded teaching science (item 9); and 44% were afraid of students asking questions that they could not answer (item 14). If there were a choice, 16% of pre-service teachers would prefer to teach science; however, 52% would prefer not to (item 18).

In general, teachers hoped that they could teach science well, but they did not have confidence. Over 50% of pre-service teachers preferred not to teach science.

As to science need, over 90% of pre-service teachers agreed that: science was as important as reading, writing, and arithmetic (item 15); children were curious about science (item 21); the teaching of science processes was important in elementary schools (item 2). Forty-six percent of pre-service teachers were interested in working with an experimental elementary science curriculum.

Teachers believed that science was necessary in the elementary school curriculum. Approximately half of pre-service teachers would like to work in an experimental science curriculum.

As to time and equipment, as many as over 70% of pre-service teachers agreed that teaching science took too much time (item 4) and effort (item 20); there were still 62% of pre-service teachers willing to spend time setting up equipment for a laboratory (item 13). This is a very encouraging finding.

Pre-service teachers' attitudes toward science laboratory were good also. Eighty percent of pre-service teachers enjoyed laboratory period (item 5) and manipulating science equipment (item 16) in their science classes. Seventy percent of pre-service teachers enjoyed helping students construct science equipment (item 12) and 58% were not afraid to demonstrate science phenomena in the classroom (item 10). However, 63% of preservice teachers feared science experiments would not turn out as expected (item 17).

In general, the majority of pre-service teachers understood the nature and importance of science and science teaching. They were willing to spend time in science classes and do experiments. But, they were afraid to teach it, mainly due to their insufficient science knowledge.

Table 1. Pre-service Teachers' Attitudes toward Science Teaching

Options Statements	SA N (%)	A N (%)	N N (%)	DA N (%)	SDA N (%)	Eff As N (%)	Missing N (%)
1. I will feel uncomfortable teaching science.	18 (2.8)	184 (28.3)	105 (16.2)	281 (43.2)	62 (9.5)	650 (100)	8 (1.2)
2. The teaching of science processes is important in the elementary classroom.	354 (53.8)	276 (41.9)	15 (2.3)	11 (1.7)	2 (0.3)	658 (100)	
3. I fear that I will be unable to teach science adequately.	32 (4.9)	233 (35.6)	104 (15.9)	253 (38.6)	33 (5.0)	655 (100)	3 (0.5)
4. Teaching science takes too much time.	138 (21.0)	429 (65.2)	53 (8.1)	35 (5.3)	3 (0.5)	658 (100)	
5. I will enjoy the lab period in the science courses that I teach.	155 (23.7)	367 (56.0)	99 (15.1)	33 (5.0)	1 (0.2)	655 (100)	3 (0.5)
6. I have a difficult time understanding science.	27 (4.1)	201 (30.6)	125 (19.1)	270 (41.2)	33 (5.0)	656 (100)	3 (0.3)

Table 1. — Continued

7. I feel comfortable with the science content in the elementary science curriculum.	29 (4.4)	281 (42.8)	177 (27.0)	158 (24.1)	11 (1.7)	656 (100)	2 (0.3)
8. I would be interested in working in an experimental elementary science curriculum.	57 (8.7)	242 (37.1)	186 (28.5)	150 (23.0)	18 (2.8)	653 (100)	5 (0.8)
9. I dread teaching science.	26 (4.0)	144 (22.0)	147 (22.5)	282 (43.1)	55 (8.4)	654 (100)	4 (0.6)
10. I am not afraid to demonstrate science phenomena in the classroom.	43 (6.6)	338 (51.5)	133 (20.3)	133 (20.3)	9 (1.4)	656 (100)	2 (0.3)
11. I am not looking forward to teaching science in my elementary classroom.	18 (2.8)	98 (15.0)	138 (21.1)	282 (43.2)	117 (17.9)	653 (100)	5 (0.8)
12. I will enjoy helping students construct science equipment.	86 (13.1)	379 (57.8)	130 (19.8)	60 (9.1)	1 (0.2)	656 (100)	2 (0.3)
13. I am willing to spend time setting up equipment for a lab.	66 (10.2)	338 (52.0)	159 (24.5)	81 (12.5)	6 (0.9)	650 (100)	8 (1.2)
14. I am afraid that students will ask me questions that I can not answer.	50 (7.6)	238 (36.2)	96 (14.6)	227 (34.6)	46 (7.0)	657 (100)	1 (0.2)
15. Science is as important as the three R's.	221 (33.6)	371 (56.5)	38 (5.8)	26 (4.0)	1 (0.2)	657 (100)	1 (0.8)
16. I enjoy manipulating science equipments.	104 (15.9)	409 (62.6)	98 (15.0)	39 (6.0)	3 (0.5)	653 (100)	5 (0.8)
17. In the classroom, I fear science experiments won't turn out as expected.	66 (10.1)	349 (53.2)	85 (13.0)	138 (21.0)	18 (2.7)	656 (100)	2 (0.3)
18. Science would be one of my preferred subjects to teach, if given a choice.	28 (4.3)	79 (12.1)	207 (31.7)	283 (43.3)	57 (8.7)	654 (100)	4 (0.6)
19. I hope to be able to excite my students about science.	168 (25.9)	424 (65.3)	45 (6.9)	10 (1.5)	2 (0.3)	649 (100)	9 (1.4)
20. Teaching science takes too much effort.	101 (15.4)	361 (55.2)	123 (18.8)	63 (9.6)	6 (0.9)	654 (100)	4 (0.6)
21. Children are not curious about scientific matters.	3 (0.5)	25 (3.9)	48 (7.4)	319 (49.2)	254 (39.1)	649 (100)	9 (1.4)

N = 658

SA : Strongly Agree.
A : Agree.
N : Not Decided or No Opinion.
DA : Disagree.
SDA : Strongly Disagree.
Eff As : Effective Answer.

Both physics-earth science and biology-chemistry tests (Table 2) indicated that pre-service teachers' attitudes toward science teaching significantly (p < .01) correlated with their basic science knowledge, gender, number of science courses taken, and scientific attitude. The correlation coefficients ranged from .22 to .34. Pre-service teachers' attitudes toward science teaching significantly correlated to science process skills and reasoning ability in the physics-earth science test. However, results in the biology-chemistry test were not the same.

Regression results revealed that basic science knowledge and gender were the first two strong predictors of preservice teachers' attitudes toward science teaching when reasoning ability, science process skills, and scientific attitudes were not included in analysis.

When all selected variables were included, 21% of the variance in pre-service teachers' attitudes toward science teaching was explained (Table 3 and Table 4). Both tests revealed that gender and scientific attitude were strong predictors of pre-service teachers' attitudes toward science teaching. Pre-service teachers with positive scientific attitudes had positive attitudes toward science teaching. Males had more positive attitudes toward science teaching than females.

Science process skills and number of science courses taken were strong predictors in the physics-earth science test and biology-chemistry test respectively. The number of science courses taken actually referred to teachers' science subject matter knowledge. Science and mathematics majors had more positive attitudes toward science teaching than non-science and mathematics majors.

Table 2. Correlations between Pre-service Teachers' Attitudes toward Science Teaching and the Selected Variables

	SCT	G	B	C	P	ES	MC	ST	GPA	GS	BSK	REA	SCI ATT	SP
	**	**									**	**	**	**
1	−.22	−.29	.06	.10	−.01	−.04	.02	.04	−.03	−.22	.23	.22	.26	.29
	**	**									**		**	
2	−.28	−.27	.07	.06	.10	.06	.01	−.01	−.09	.14	.25	.06	.34	.16

** P < .001
1 : Physics-Earth Science Test N = 267
2 : Biology-Chemistry Test N = 220
SCT : Number of Science Courses Taken
1: Science and Math. Major
2: Literature and Social Science Studies Major
3: Music, Arts and Physical Education
G : Gender M:1, F:2
B : Biology
P : Physics
MC : Method Course
GAP : Grade Point Average
BSK : Basic Science Knowledge Test
SP : Science Process Skills
C : Chemistry
ES : Earth Science
ST : Student Teaching
GS : General Science
REA : Reasoning Ability
SCI ATT: Scientific Attitude

Table 3. Regression Results of Selected Variables to Pre-service Teachers' Attitudes toward Science Teaching (Physics-Earth Science Test)

Step	Variable	Multiple R	R Square	Significance level
1.	Gender	.30	.09	.00
2.	Science process skills	.40	.16	.00
3.	Scientific attitude	.45	.21	.00

Table 4. Regression Results of Selected Variables to Pre-service Teachers' Attitudes toward Science Teaching (Biology-Chemistry Test)

Step	Variable	Multiple R	R Square	Significance level
1.	Scientific attitude	.34	.12	.00
2.	Gender	.43	.19	.00
3.	No. of science Courses taken	.46	.21	.00

V. Conclusions and Discussion

Findings of this study indicated that over 90% of pre-service elementary school teachers in the Republic of China realized that science teaching took time and effort. They also agreed that science was as important as the three R's. Over 60% of pre-service teachers were willing to teach science and do experiments in classes. However, 63% of pre-service teachers were worried about the experiment results not coming out as expected and 44% were afraid of students asking questions which they could not answer in class. Lack of confidence mainly affected pre-service teachers' attitudes toward science teaching.

Forty-four percent of pre-service teachers felt that they were able to teach science, but another 44% felt that they were unable to teach science adequately.

Compared to the findings in the United States (Weiss, 1978), pre-service teachers' willingness to teach science in elementary schools in the Republic of China was gratifying. Improvement of elementary school science teaching seems easier in the Republic of China than the United States since the majority of pre-service teachers were willing to teach science. However, the finding that teachers' insufficient science background affected their attitudes toward science teaching mainly was the same in both countries.

Regression results indicated that selected variables explained 21% of the variance of pre-service teachers' attitudes toward science teaching: scientific attitude, gender, science process skills, and the number of science courses taken were strong predictors.

Teachers' attitudes toward science teaching significantly correlated with their reasoning ability in the physics-earth science test (Table 2). It was also reported in the previous study that the same group of students' scientific attitudes, science process skills, and reasoning ability were significantly correlated ($p < .001$, $r = .15$ to $.42$) (Lee, 1990). Multiple significant correlations among these variables indicated that there must be some common attributers. It is the author's hunch that some of these common attributers might be related to pre-service teachers' cognition of the nature of science and their science knowledge, which are possibly key points for further investigations.

Final grades in science courses, student teaching, science method course, and GPA were not significantly correlated to pre-service teachers' attitudes toward science teaching. Non-significant correlation between GPA and teachers' attitudes toward science teaching was acceptable since top students are not necessarily fond of teaching science. However, non-significant correlations between final grades of science courses and science method course indicated that there must be some incongruence between teachers' preparation and pre-service teachers' science teaching ability. Non-significant correlations implied that science courses and science method course in teachers' colleges had to be evaluated to check if these courses were too much theory-oriented since the basic science knowledge tests in this study were designed to focused on the basic science concepts which were covered in elementary school science curriculum and test results were significantly correlated with teachers' attitudes toward science teaching.

There was still 80% of the variance not explained. Further deep investigations of teachers' attitudes toward science teaching are recommended.

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References

Anderson, R.D., & Druva, C. A. (1983). Science teacher characteristics by teacher behavior and by student outcomes: A meta-analysis of research. *Journal of Research in Science Teaching, 20*(5), 467-479.

Atwood, R. K., & Howard, M. N. (1989). *Teacher's perceptions of barriers in utilizing SCIS-II.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Blosser, P.E. & Howe, R.W. (1969). An analysis of research on elementary teacher education related to the teaching of science. *Science Education, 6*(5), 50-60.

Chen, G.T., Lee, T.Y., Hsyu, Y.J., & Hsiung, Z.T. (1989). *A need assessment of science teaching in elementary schools and the design of some science activities.* Taiwan Provincial Taipei Teachers College, Department of Science and Mathematics Education.

DeBruin, J.E. (1977). The effect of field-based elementary science teacher education program on undergraduates' attitudes toward science and science teaching. In M.K. Piper & K.D. Moore (eds.), *Attitudes toward science: Investigations,* 42-47, ERIC/SMEAC, Ohio State University.

Dobey, D.C., & Schafer, L.E. (1984). The effects of knowledge on elementary science inquiry teaching. *Science Education, 68*(1), 39-51.

Earl, R.D., & Winkeljohn, D.R. (1977). Attitudes of elementary teachers toward science and science teaching. *Science Education, 61*(1), 41-45.

Fraser-Abder, P., & Shrigley, R. L. (1980). A status study of the science attitudes of elementary school teachers in Trinidad and Tobago. *Science Education, 64*(5), 637-644.

Gabel, D.L.(1981). Attitude toward science and science teaching of undergraduates according to major and number of science courses taken and the effect of two courses. *School Science and Mathematics, 81*(1), 70-76.

Gabel, D.L., & Rubba, P.A. (1977). *Attitude changes of elementary teachers trained and selected as model science teachers.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Cincinnati, Ohio, ED135 646.

Ginns, I.S., & Foster, W.J. (1983). Preservice elementary teacher attitudes to science and science teaching. *Science Education, 67*(2), 277-282.

Grossman, P.L., Wilson, S.M., & Shulman, L.S. (1989). Teachers of substance: Subject matter knowledge for teaching. In M.C. Reynolds (eds.), *Knowledge base for the beginning teachers,* 23-36. Pergamon press.

Haury, D.L. (1989). The contribution of science locus of control orientation to expressions of attitude toward science teaching. *Journal of Research in Science Teaching, 26*(6), 503-517.

Heter, J.R. (1985). How teacher attitude effects student motivation. *Decade+*, Fall, 50-51. ED 269 368.

Jaus, H.H. (1977). An analysis of the relationship of preservice elementary teachers' attitudes toward science and science teaching planning practices. In M.K. Piper and K.D. Moore (eds.), *Attitudes toward science: Investigations,* 48-50. ERIC/SMEAC, Ohio State University.

Kramer, D.C. (1979). Science attitude change in preservice elementary teachers during an activity-oriented biology course. *School Science and Mathematics, 79,* 294-298.

Knight, L.B. (1975). The evaluation of an early experience in science teaching. ED 108 870.

Koballa, Jr. T.R. (1986). Teaching hands-on science activities: Variables that moderate attitude-behavior consistency. *Journal of Research in Science Teaching, 22*(6), 555-564.

Lee, T.Y. (1982). A survey of elementary schools science teaching. *Annual research reports of Taiwan Provincial Hsin-Chu Junior Teachers College, 8,* 251-340.

Lee, T.Y. (1990). *A comparisions of preservice teachers' cognitive development, science process skills, and scientific attitude with different science background.* Final report for the National Science Council research project (NSC78-0111-S003-35).

Lee, T.Y. (1990). *The status of science learning in teacher colleges in the Republic of China.* Final project report for the National Science Council. Taipei, Taiwan, R.O.C.

Lucas, K. B., & Dooley, J. H. (1982). Student teachers' attitudes toward science and science teaching. *Journal of Research in Science Teaching, 19*(9), 805-809.

Lutz, J.H., & Orlich, D.C. (1988). *A model to improve preservice education science teacher development.* Final project report. ED 296 886.

Moore, R.W., & Sutman, F.X. (1970). The development field test and validation of an inventory of scientific attitudes. *Journal of Research in Science Teaching, 77,* 5-94.

Okey, J.R., Wise, K.C., & Burns, J.C. (1982). Integrated process skills test. In Matheis, F. E. *et al.* (1985). *A study of the logical thinking skills, integrated process skills, and attitudes of junior high school students in North Carolina.* Ed 285 754.

Pedersen, T.E., & McCurdy, D.W. (1990). *The effects of hands-on minds-on teaching experiences on attitudes of preservice elementary teachers.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, Ga., April 8-11, 1990. ED 317 437.

Piper, M.K., & Moore, K.D. (1977). *Attitudes toward science: Investigations.* SMEAC Information Reference Center, Ohio State University.

Reed, B., Crocker, B., & Shaw, Jr. E. L. (1989). *Effects of encouragement or discouragement for using hands-on science activities upon teaching style.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Riley, J.P. (1975). *The effect of science process training on preservice elementary teachers' process skill abilities, understanding of science, and attitudes toward science and science teaching.* ED 102 019.

Roadrangka, V., Yeany, R.H., & Padilla, M.J. (1983). Group test of logical thinking. In Mattheis, F. E. *et al.* (1985). *A study of the logical thinking skills, integrated process skills and attitudes of junior high school students in North Carolina.* ED 285 754.

Sherwood, R.D., & Gabel, D. (1980). Basic science skills for prospective elementary teachers: measuring and predicting

success. *Science Education, 64*(2), 195-201.

Shrigley, R.L. (1974). The correlation of science attitude and science knowledge of preservice elementary teachers, *Science Education. 58*(2), 143-151.

Stake, R.E. *et al.* (1978). Case studies in science Education. Washington, D.C., U.S Government Printing Office. ED 166058, 166 059.

Stefanich, G.P., & Kelsey, K.W. (1989). Improving science attitudes of preservice elementary teachers. *Science Education, 73*(2), 187-194.

Stepans, J., & McCormack, A. (1985). *A study of prospective elementary teachers: A research report.* ED 266 024.

Taiwo, D. (1980). The influence of previous exposure to science education on attitudes of preservice science teachers toward science teaching. *Journal of Research in Science Teaching, 17*(4), 315-320.

Thompson, C.L., & Shrigley, R.L. (1986). What research says: Revising the science attitude scale. *School Science and Mathematics, 86*(4), 331-343.

Weiss, I.R. (1978). *Report of the 1977 national survey of science, mathematics, and social studies education.* Center for Educational Research and Evaluation Research Triangle Park, North Carolina.

Westerback, M.E. (1982). Studies on attitude toward teaching science and anxiety about teaching science in preservice elementary teachers. *Journal of Research in Science Teaching, 19*(7), 603-616.

Westerback, M.E., Gonzalez, C., & Primavera, L.H. (1985). Comparison of preservice elementary teachers anxiety about teaching students to identify minerals and rocks and students in geology courses anxiety about identification of minerals and rocks. *Journal of Research in Science Teaching, 22*(1), 63-79.

Westerback, M.E., & Long, M.J. (1990). Science knowledge and the reduction of anxiety about teaching earth science in exemplary teachers as measured by the science teaching stat-trait anxiety inventory. *School Science and Mathematics, 90*(5), 361-374.

國小職前教師之自然科教學態度及其與所選擇變因之相關研究

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摘　要

本研究探討國小職前教師對於教自然科學的態度及影響此教學態度的變因。所選擇之變因包括基本科學知識、各科學課程、自然科教學研究、教學實習等的學期成績與畢業總成績及修習自然科學科目的數目、性別、科學過程技能、科學態度、認知推理能力等。民國79年6月的師專結業學生658人參與測試，資料經由SPSSX套裝軟體分析各變因的頻率及相關，並做迴歸分析。研究結果顯示：90%的國小職前教師同意科學的重要性並瞭解科學的本質，不過近50%的人怕教自然科學。迴歸分析的結果並顯示所選擇的變因可解釋21%的自然科教學態度之差異。其中科學態度、性別、科學過程技能及修習自然科學課程的數目爲強預測變因。

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The Recognition of Icons for Chinese Students

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ABSTRACT

Icons could be seen as a kind of symbol to communicate ideas (Shirk, 1988). Moreover, Moray (1981) diagnosis in "feature in man-machine system" suggested that in order to have a meaningful "communicate idea", one must find, integrate, and interpret all of the data at the right time. In other words if there were no proper use for learners, it might result in frustration (because of operating unsmoothly) to learners (Shirk, 1988). Based on these ideas, the focus of this research was to examine if icons borrowed from other countries were suitable for Chinese students. The results of this study indicated abstract icons are more difficult to be recognized by Chinese students than those of semi-abstract and concrete, generally. However, the older the samples, the more easily abstract icons were recognized.

Key words: icons recognition

I. Introduction

From the development of a man-machine system, the interaction between man and computer became simple. Baker (1982) once discussed "some experiment in man-machine interaction relevant to computer-to-computer assisted instruction (CAI)". In his study, man-machine interaction included: (a) tough sensitive keypads, (b) a lighter, (c) a joystick, and (d) a hand print terminal, four ways of man-machine affects interaction. Obviously, "mouse" was not available at that time, so there were no problems about icons. Then the Apple company designed the Macintosh system which used "mouse" as a tool of the interaction between man and machine; that was a great change in the development of CAI Authoring Language. So far, almost all the program designs of CAI or CBI (computer-based instruction) can use a mouse to put icons to work.

Shirk (1988) thought the importance of icons' design was to hold onto the convention of the "real world". That was the symbol of icons must be concerned with the concept of users which was designed by their metaphor and mnemonics. While mnemonics was about memory capacity (including about term and metaphors) yet metaphors are related to culture, semantics and syntax, and cognition (Cormac, 1985). For example, the semantics of "key" were used as an adjective, such as key menu, key page but in Chinese language family was not used as an adjective. Besides "key", there was the use of a noun as a verb, such as chair the table, table the chairs, book a bad guy. Those were metaphors application and they were hardly recognized by Chinese learners or users. That was the consequence of applying directly the other countries' icons.

The main goal of the use of icons was to base on learners' schemata to build up visual image to decrease the process time and get the mnemonics effect. According to this goal, Tripp(1988) illustrated metaphor and learning to demonstrate the principles of metaphor using. So Shirk defined icons as a metaphor; their principles could be adjusted as the principles of using icons. They were: (1) use icons to present procedures which were complex, unfamiliar, or abstract; (2) when using several icons coordinate their meaning; (3) be sure the icons were familiar to the target audience, and (4) consider the logic in application of each icon used.

Besides the four principles, Shirk (1988) has presented the three principles of icons use: consistency, clarity and simplicity. If one usually emphasized simplicity too much, it was difficult to stress clarity. When the condition was contrary, the fact was contrary. Moreover Needham (1969) in his book "The Grand Titration" mentioned that the Chinese thinking process was a more holistic process; while the western people's process was a more serial process. Generally speaking, the simpler the graphic was, the more advantageous to the holistic process. Based on this idea, the simplicity or clarity of design in icons might also have different tendencies because of thinking process. But Blattner *et al.* (1989) labeled types of icons as: (a) abstract, (b) representational, and (c) semi-abstract (a combination of representational and abstract icons). Among those three types of icons, the more abstract it was, the more emphasis on shape in visual recognition; and abstract icons needed learners to distinguish more from their reasoning and expectation. On the other hand, representational icons laid more stress on object, shape and texture, but they needed more prior knowledge for the students to tell them apart.

In addition to the effect of the Icons characteristics on icons, use other factors also affected the icons' use. Shneiderman (1987) mentioned human factors of interactive software. The five measurable human factors could be defined as: (1) time to learn, (2) speed of performance, (3) real errors by users, (4) subjective satisfaction, and (5) retention over time.

According to those discussions, the main purposes of the research were: (1) what kinds of icons are not fit for Chinese students? In other words, do icons have consistency and simplicity problems for Chinese students? (2) to those who are not acquainted with icons, if those students practice more to increase familiarity, what is the rate of their retention?

The design of icons was based on the learners' metaphors and mnemonics as mentioned above. The samples of this study must take age and sex into consideration because of the differences in short-term memory, long-term memory and cognitive development. For example, Piaget's cognitive development is divided into sensorimotor period, preoperational period, concrete operational period, and formal operational period. Burner clarifies them as enactive representation, iconic representation and symbolic representation. It showed that the variables in age in symbols identification had much difference (Hart and Moore, 1971). Therefore, age and sex were the major concerns regarding research-dependent variables.

II. Method of This Study

The definition of icons (Jones, 1989 ; Shirk, 1988) was to produce visual recognition for human-computer interaction. Yet, the visual recognition abilities is relevant to prior knowledge and reasoning ability (Ullman, 1989). That is to say, in Piaget's opinion the four steps of recognition development could be classified as to choice of research samples.

Therefore, the method of this study included two steps. The first step was to understand the students' acquaintance with icons; the paper and pencil test was taken by students to identify what icons should be included in experimental study. The second step was to take junior high school students as the basic sample, and by random selection, test process of retention rate. 20 boys and 25 girls of first grade students in junior high school, 25 boys and 16 girls of second grade students in junior high school, 24 boys and 17 girls of third grade students in junior high school students, participated in the examination of icons' familiarity.

In other words, in the first step of this study, 36 icons were selected to test the recognition tendency of students as the reference for further application in icon using. The second step, in order to analyze which icons were fit for students, was to develop a simple graphic authoring tool. Students were allowed to practice with those icons, and students to complete a castle drawing to examine the recognition ability with icons' graphics.

III. Sampling Characteristics

Students' operating times and the selection and reviewing of icons' function were the basic data collected by computer. The first step tested students including 330 primary school students, 608 junior high school students and 380 senior high school students. These three types of educational background included 985 boys and 333 girls; the total was 1318 students. The distribution of the age of the tested students: 350 students were under the age of 12; 315 students were between 13-14; 368 students were between 15-16, and 306 students above the age of 17. The rate of using icons experiences: there were 152 (45.8%) primary students; 160 (25.9%) junior high school students; 178 (44.3%) senior high school students who have used icons. The total students of the second step are 127 people. There were 69 boys and 58 girls. Being classified by grade, the first was 45, the second 41, the third 41.

IV. The Result of This Study

The findings of this study are described:

On the students' recognized ability in icon types, the research results indicated as follows:

1. When they distinguished the various types of icons, students of different educational backgrounds had obvious differences in their testing scores. The scores of senior high school students were higher than junior high school and primary school students, in abstract and semi-abstract types of icons, and better than primary school students in abstract, semi-abstract and representational types. To sum up, the recognized ability of senior high school were better than those of primary school students, but there were no obvious differences between junior high school students and primary school students in distinguishing the function of icons.

2. Regarding which icons were more easily or less easily recognized by students, and if there were any differences in distinguishing icons due to different educational background, the results indicated in Table 1.

Different educational background students exhibited the same ability in the easiest discrimination of the top 5 icons types. There were 8 kinds of icons which appeared in different educational background in the easiest discrimination of top 5 icons types, 6 of them belonged to representational types. It could be concluded that the representational icons were more easily accepted by students. Furthermore, the primary school students more easily accepted the icons which transfer directly from Chinese words.

Besides the difficulty in recognizing the function of icons in different educational background, (also displayed the evidence as Table 1) indicated sex and age as the important variables influencing icons' recognition. In order to realize if there were similar conditions in sex and age background, the results indicate follows:

(1) Regarding the type of icons, in comparing age and sex, in two factors analysis, the main effect gets to the significant difference [$F(age) = 4.87$, $p < 0.05$; $F(sex) = 10.73$, $p < 0.5$], as to the interaction there was no clearly difference between age and sex in the abstract types of icons.

(2) The Scheffe testing was applied to this study, and the result indicated that students of "above age of 17" were significantly higher than those of "below age of 12", "age of 13-14", and "age of 15-16" in abstract types of icons. Regarding sex, boys had significantly higher recognition ability than girls in abstract types of icons.

(3) As to the interaction, the students of "age of 14-15" boys had significantly higher recognition ability than girls in "semi-abstract" icons and group; there was no significant difference between boys and girls in order age groups.

Furthermore, the results of icons' recognition by sex and age were:

(1) The result of "representational" icons in comparing age and sex showed that the major effect gets to the significant level [$F(age) = 11.24$, $P < 0.1$; $F(sex) = 4.30$, $P < 0.05$], as to the two-way ANOVA; there is no significant difference.

(2) Regarding representational icons in different sex and age, this result showed that the student of "above the age of 17" had significantly higher recognition ability than those of "below the age of 12", "age of 13-14" and "age of 15-16" in representational icons. Besides, boys had significantly higher recognition ability than girls as to representation icons.

Table 1. The Icon Recognition Rate with Different Age Groups

		5th Grade			8th Grade			11th Grade	
	Icons' no.	Recognized %	Icon type	Icons' no.	Recognized %	Icon type	Icons' no.	Recognized %	Icon type
5 easiest icon recognition	11	90	A	11	86	A	11	92	A
	24	86	B	19	83	A	24	91	B
	23	80	A	24	83	B	19	89	A
	1	79	A	23	81	A	27	85	C
	18	77	A	27	75	C	13	82	A
5 most difficult icon recognition	17	11	C	17	14	C	3	12	A
	3	16	A	3	19	A	17	14	C
	25	25	B	25	23	B	25	18	B
	13	29	A	33	29	C	26	29	B
	9	33	A	35	29	C	35	31	C

Note: A type: representational B type: semi-abstract C type: abstract

Table 2. Sex, Age, Learning Experience in the Icons Recognition Testing of 36 Types of Icons

No.	%	Order	1. Sex	2. Age	3. Learning experience	Types
1. Abstract						
2.	55%	18.5	boys > girls**	**	yes > no**	Fill
4.	40%	30	girls > boys**	*	yes > no**	Arbitrary lines
8.	44%	25		*	yes > no**	Fill or bucket
10.	69%	19	boys > girls**		yes > no*	Mark area
17.	13%	35				Hollow polygon
22.	42%	26.5	boys > girls**		yes > no**	Filled polygon
27.	77%	5		**		Hollowed rectangle
29.	78%	4		*	no > yes**	Cocentric circles
33.	41%	28.5	boys > girls**	**	yes > no**	Path
35.	30%	33				Change paper
Total	49%		boys > girls**	**	yes > no**	
2. Semi-abstract						
7.	56%	17		*	yes > no**	Erasing part of graph
12.	42%	26.5				Text
16.	66%	13	boys > girls**	***	yes > no**	Spline
24.	86%	2		*		Arbitrary lines
25.	22%	34				Fill
26.	32%	32				Erase all
28.	68%	10		**		Arbitrary lines
30.	65%	14	boys > girls**	**	yes > no**	Save file
31.	50%	22	boys > girls**	**	yes > no**	Erase file
32.	48%	23	boys > girls**		yes > no**	Open file
34.	48%	11.5	boys > girls**	**		Print a file
36.	67%	28.5	boys > girls**	**	yes > no*	Highlighting
Total	54%		boys > girls**	**	yes > no*	
3. Representational						
1.	72%	6.5		**	yes > no**	Text
3.	16%	36	girls > boys*			Pencil or sketch
5.	57%	16	boys > girls**	**	yes > no**	Brush
6.	72%	6.5	boys > girls**	*	yes > no*	Spray
9.	38%	31	boys > girls**		yes > no*	Plotting a point
11.	89%	1		**	yes > no**	Erasing part of graph
13.	60%	15	boys > girls**	**		Rectangle
14.	54%	20	girls > boys**	**	no > yes**	Rounded rectangle
15.	55%	18.5	girls > boys**	**	yes > no**	Oval or ellipse
18.	67%	11.5	girls > boys**	**		Regular polygon
19.	83%	3	boys > girls**	**	yes > no**	filied-rectangle
20.	52%	21				Filled-rounded rectangle
21.	47%	24			no > yes**	Filled-oval
23.	71%	7	boys > girls**		yes > no*	Filled-regular polygon
Total	60%		boys > girls**	**	yes > no**	
Total	55%			**	yes > no**	

**$p < .01$, *$p < .05$

Moreover, the icon recognition of 36 types in different sex, age and learning experience (with icons operation before this experiment) was analyzed by Chi-square test, and the results are generalized as Table 2.

(3) In these 36 icons, there were 23 kinds of icons having significantly different levels because of "sex", among them, boys higher than girls in 18 kinds of icons; on the other hand, there were 5 kinds of score with girls' higher than boys'. There were 27 kinds of icons pointing to a significant difference because of "age." The cause of these differences resulted from the significantly higher ability of "below 12 age," "age of 13-14" and "age of 15-16" groups. As to the "learning experiences," these were 25 kinds of icons pointing to the significantly different levels, and 22 kinds of them were the students of "with learning experiences" higher than those of "without learning experiences." "Without learning experience" students' scores had 3 kinds of icons higher than those of "with learning experiences."

After the paper and pencil testing, at the first step 20 kinds of icons were selected from the 36 kinds of icons at the second step. Then first grade, second grade and third grade students in junior high school were invited to practice those icons through finishing a castle drawing on the computer. Data collection indicated the age, grade, operating condition, times of using icons, times of using icons and help explanation. Moreover, the data were analyzed and the results of the study were:

(1) The drawing speeds were divided into fast, middle and slow to examine the drawing speed difference with age groups. However there was no difference in the speed of drawing icons in spite of different grade.

(2) There were significant differences between "Function choice" and "Function review" in this study ($r = 0.70$, $p < 0.01$). To compare these two, the most significant icons were:

(1)	No. 9	Pencil or sketch
(2)	No. 36	Highlighting
(3)	No. 7	Eraser
(4)	No. 26	New
(5)	No. 2	Fill
(6)	No. 30	Save

In comparing with that of paper and pencil testing step, those 6 kinds of icons were difficult to be understood by learners. In other words, these 6 kinds of icons were not satisfactory for the habit of "to see and to know" for Chinese learners.

(3) In order to understand the time consumed by students of different ages and sex, allowed to review "the function of icons." The results pointed to the significant differences in different sex and age ($F = 60.02$, $p > 0.01$). That was under the influences of the times in "using icons function." As to the major effect and interaction in "sex" and "age," they did not show significant difference.

(4) As the comparative analysis of the subjects of different sex and drawing speed in the times of reviewing "the function of icons,"-the result of statistical analysis reached the significant difference ($F = 57.15$, $p < 0.01$). Regarding different sex, the drawing speed and in viewing "the function of icons," the major effect and interaction did not show a significant difference.

V. Conclusion

Owing to the improvement of interface in the design of man-computer interaction, CAI could decrease the worry when students learned with a computer; the educational effect of students also could be improved tremendously. Especially when using a mouse to control the learning process, students were more interested in learning with computer. Icons were often used as the interface between mouse and computer in CAI processing. Furthermore, the effectiveness of CAI would be influenced by the good designs of icons. Whereas, the design of icons has something to do with culture, although the most common design of icons often derived from American culture, it is necessary to examine which icons were suitable for Chinese students.

The summaries of this research were as follows:

(1) The icons could be divided into abstract,semi-abstract and representational types; the abstract icons gained the lowest recognition ratio for Chinese students.

(2) Boys got higher scores than girls in different types of icons.

(3) Samples "above the age of 17 group" got the higher ability than the others in recognizing different types of icons.

(4) Regarding sex and age, these two variables have the interaction in the scores of "semi-abstract" icon recognitions. The result indicated the age of 14-15 group in "semi-abstract" icons, boys scored higher than girls did. No matter which sex, to age of 16-17 group, subjects exhibited higher recognition rate than the other groups in semi-abstract icon recognitions.

Appendix

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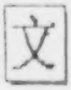

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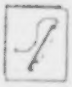

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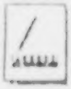

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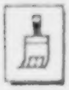

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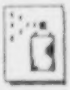

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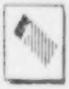

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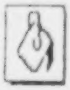

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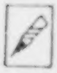

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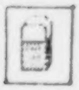

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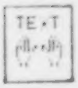

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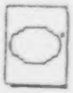

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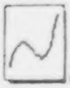

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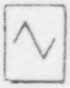

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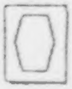

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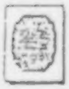

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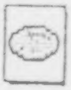

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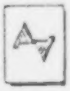

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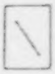

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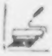

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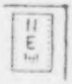

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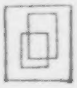

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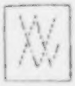

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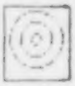

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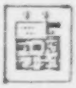

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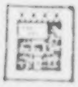

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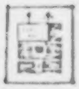

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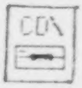

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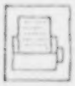

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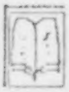

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References

Barker, P.G. (1982). Some experiments in man-machine interaction relevant to computer-assisted instruction. *British Journal of Educational Technology, 13*(1), 65-75.

Blattner, M.M., Sumikawa, D.A., & Greenberg, R.M. (1989). Earcons and icons: Their structure and common design principles. *Human-Computer Interaction, 4,* 11-44.

Cormac, E. R. M. (1985). *Acognitive theory of metaphor.* Cambridge. Ms: The MIT Press.

Hart, R. A., & Moore, G.T. (1971). *Development of spatial cognition: A review.* Chicago: Environmental Research Group.

Jones, M. K. (1989). *Human-computer interaction: A design guide.* Englewood Cliffs, New Jersey: Educational Technology Publications.

Moray, N. (1981). The role of attention in the detection of errors and the diagnosis of failure in man-machine system. In J. Rasmassen, & W.B. Rouse (eds.). *Human detection and diagnosis of system failures.* N.Y.: Plenum Press.

Needham, J. (1969). *The grand titration: Science and society in east and west.* George Allen & Unwin Ltd.

Shirk, A.N. (1988). *Using icons in computer based instruction.* Presented at the 30th International ADCIS Conference, Philadelphia, PA.

Shneiderman, B. (1987). *Designing the user interface: Strategies for effective human-computer interaction.* Singapore: Addison-Wesley.

Tripp, S.D. (1989). *Metaphor and instruction.* Presented at the 31th International ADCIS Conference, Washington,D.C.

Ullman, S.(1989). Aligning pictorial descriptions: An approach to object recognition. *Cognition, 32*(3), 193-254.

中國學生對圖素的認知

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摘　要

電腦輔助敎學(CAI)，由於人機介面設計的改造，減少學生操作上的憂慮，其學習效果也大爲提昇。尤其是在利用滑鼠來控制學習運作，學生自然樂於在電腦上進行學習。而滑鼠與電腦間，通常由Icons（圖素）來做介面，圖素設計的好壞對CAI的學習有直接的影響。又圖素設計通常和文化背景有關。然目前國內CAI的圖素設計大都沿自美國，到底有那些圖素不適合中國學生是値得探討的。

本研究擬抽樣國小、國中及高中學生，以紙筆測驗學生不熟悉之圖素，再進一步讓學生應用圖素，由學生利用圖素時，查驗圖素的功能說明來瞭解，有那些圖素是因文化差異而造成圖素辨認及應用上的困難。本研究結論摘要如下：

一、就圖素而言，可分爲抽象、半抽象及具體三類圖素，受測驗學生在抽象圖素的辨識率較其他兩項爲低。

二、男生在辨識圖素各項目的得分皆較女生爲高。

三、17歲以上學生在辨識圖素各項目的得分較他組學生爲高。

四、高中（職）學生在辨識圖素素各項目的得分較國中、國小學生爲高。

五、性別與年齡二變項在半抽象圖素得分上有交互作用存在，經單純主要效果的事後考驗（Scheffe法）得知：14－15歲年齡的學生在辨識半抽象圖素的得分男生較優於女生，且無論性別爲何，16－17歲年齡的學生在辨識半抽象圖素得分皆優於其他三組。

六、在上機實驗時發現學生在複習該項圖素素說明的次數，受到其選擇該項圖素功能次數多寡的影響，在排除該項影響因素後，性別、年級與繪圖時間三變項在選擇圖素說明次數（亦即學生並不清楚圖素的功能）的主要效果，交互作用效果的比較上皆未達顯著水準。

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A Genetic Decomposition of Geometric Transformations with an Outline of an Instructional Treatment Design through Logo

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ABSTRACT

This study tried to find out how the concepts of translation, reflection, and rotation were developed and how they were learned. The study is based on a system of approaches proposed by Dubinsky. the van Hiele Levels were used to develop the questions, and eighteen preservice elementary school teachers were interviewed. Four levels were distinguished by the results of the interviews. A description of a construction process for developing schemata of the transformations was obtained. Based on the description, a practical instructional treatment was outlined. It consisted of computer experiences designed to stimulate the students to move along the cognitive constructions for developing schemata for the geometric transformations.

Key words: reflective abstraction, genetic decomposition, operational definitions

I. Introduction

Many mathematicians and mathematics educators realize that geometry is an essential topic in mathematics. However, Hoffer (1981) found that most freshmen at the University of Oregon disliked and did not understand geometry courses during high school. Another educator, Noss, (1987) indicated that geometrical ideas were difficult for many children. He suggested Logo programming as a method to help children learn geometrical concepts. As it has been seen, geometrical ideas are difficult at all levels from elementary school through college. The evidence which is accumulated from a number of studies (Clements and Battista, 1989; Mayberry, 1983; McDonald, 1989) points out that many efforts have been made to investigate these concepts in order to facilitate students' learning of them. During the last several years, some mathematicians, such as Craine (1985) and MacPherson (1985), have carefully scrutinized the basic ideas of geometry and have attempted to try to reconstruct the mathematics curriculum in order to help students to have a better understanding of geometrical ideas. From Craine and MacPherson's works, it can be seen that geometrical transformations play an important role in their new curriculum. The transformations considered here include the distance-preserving isometries — translation, rotation, and reflection. Moreover, Williford (1972) suggested that understanding the concept of transformations can facilitate students' learning of other branches of geometry. Many mathematics educators have studied this concept. Ernest (1988) investigated the effects of using computers to help students learn those transformations. Kidder (1976) investigated the effects of transformation type and age of children on students' understanding of transformations. Schultz and Austin (1983) investigated the effects of transformation type and direction on students' understanding of transformations.

In this study, I would like to try to answer the question, "What can we do to help students understand the concept of these three geometrical transformations?" Investigation is focused on how the concept of these transformations is developed and learned. Precisely, the study will be based on a system of approaches proposed by Dubinsky (1991a) which consists of three components: (1) a general theory (relying heavily on the ideas of Piaget) of advanced mathematical concept construction, (2) the investigator's understanding of a mathematical concept, and (3) observations of students as they try to construct a mathematical concept. Dubinsky claimed that this system of approaches could be used to describe any advanced mathematical concept together with its acquisition. The most important implication of Piaget's theory and Dubinsky's theory is that if students want to understand a concept, they have to construct knowledge from their own actions on the environment. They must construct something in their own minds. For educators, if the objective of education is to help students' acquisition of knowledge, educational methods need to be consistent with the way students acquire knowledge. Therefore, educators should develop or use (if it exists) a genetic decomposition of that knowledge in order to encourage disequilibrium and permit students to carry out equilibration, in their own ways, through active methods. Thus, the objective of the study is to work out a genetic decompositon of the concept of translation, reflection, and rotation. We hope that something can be found such as: how the concepts of translation, reflection, and rotation are constructed by students; which kinds of reflective abstraction are needed in order to understand them.

II. Methods

1. Subjects

The subjects, 18 pre-service elementary school teachers, were chosen voluntarily from a geometry course at Purdue University. From previous experience we knew that students enrolled in this course had learned little mathematics in high school. In Purdue University there are two mathematics courses designed for those who would like to be elementary-school teachers. This geometry course is the second course. This means that the subjects should have had at least a one-semester mathematics course at the college level. The concepts of reflection, translation, and rotation play an important role in this geometry course, and the course is taught through classroom lecture. The data were collected by interviewing students after the related materials were covered.

2. Instruments

In carrying out the study, a set of questions was designed for the interviews. The questions were reviewed by a mathematics educator and an instructor who taught the same course and was not involved in the study. The questions were revised according to their suggestions. Three assumptions were made and used as guidelines for the development of the questions.

(1) Students' mental development in geometry follow a sequence of five levels, identified by van Hiele (Hoffer, 1981). Van Hiele's research indicated that for students to function adequately at one of the advanced levels, they must have mastered large chunks of the prior levels. Otherwise, students may perform only algorithmically on the higher level.

(2) The students who were enrolled in a required science course for elementary education majors at Georgia College were not ready for a formal deductive geometry course (Mayberry, 1983). Based on literature review, discussions with other teachers, and my own experiences, I have made the assumption that the pre-service elementary education teachers at Purdue University are not ready for a formal deductive geometry course. In other words, what students should perceive after the instruction are the definition and properties of the transformations and the relationships between them.

(3) Students should develop five basic skills — visual, verbal, drawing, logical, and applied — in geometry (Hoffer, 1981). Hoffer gave descriptions of various skills that might be expected of the students who are not ready for formal deductive geometry courses.

What does it mean to understand those three transformations? Based on the three assumptions, students need to:

A. Define the transformations verbally (verbal skill).

B. Given certain graphs, construct the image of them under a certain transformation (drawing skill).

C. Given two congruent graphs, recognize the relationship (transformation) between them (visual skill).

D. Given two congruent graphs, give the reason why such relation (transformation) exists between them (applied skill).

E. Use the properties of transformations to determine that those three transformations are mutually exclusive (logical skill).

According to the above tests three situations are designed for the questions. In situation 1, each subject is randomly assigned one of the three transformations and is asked to answer the questions (Q1 and Q2).

Q1 Define the transformation.
Q2 Give an example of the transformation.

In situation 2, a figure with a transformation the same as the transformation in situation 1 is presented. The subject is asked to answer the questions (Q3 and Q4).

Q3 Describe the figure verbally.
Q4 Describe the image of graphs under the transformation.

In the third situation, three figures (each has two congruent graphs) are presented, one after the other, and the student is asked to answer the questions (Q5 to Q8) for each of these three figures.

Q5 Describe the figure verbally.
Q6 Describe which transformation can transfer one graph to the other.
Q7 Explain how to find the answer.
Q8 Explain whether the other two transformations are able to make the transfer.

3. *Procedures*

After the related materials are covered, each subject is interviewed individually and asked to answer the questions in the question set in order to determine the nature of the student's understanding of the concept. A small, quiet room is selected as an interviewing room. The whole period of each interview is recorded by cassette player, and is transcribed. Since the purpose of the study is to find out how the concept of these three transformations is developed and how it is learned, a cognitive conflict is recognized when subjects are unaware of their mistakes. Hints are given to the students to determine how far they are able to go in the development of the concept.

III. Results

The results of the interviews are analyzed by using the method of content analysis (Kerlinger, 1986). The universe of content in the study is all verbal replies to the questions asked the subjects. There are four categories: (1) definition of transformations, (2) single-point movement, (3) identification of transformations, and (4) figure movement. The categories used here are based on my understanding of the concept and the analysis of the data. The unit of analysis is themes which are a sentence or sentences that can be placed under one of the categories. In order to establish reliable coding, operational definitions are necessary. The themes that will be assigned to the category of definition of transformations are clear definitions, and evidence that the subject possesses the concept of the definition of transformations. In other words, after students give the definition of a transformation verbally, the interviewer will continue to ask them to manipulate some points in order to test against their previous responses. Based on the fact that the preservice elementary teachers at Purdue University are not ready for a formal deductive geometry course, the definition of transformations above refers to the informal definition, such as flip for reflection, turn for rotation, and slide for translation. There are two important components for making a transformation. These are the location and the orientation (facing) of the transformation image. Students have to be aware of these two components in order to understand the concept. These two components can be tested by single-point movement (emphasizing location) and identification of transformations (emphasizing orientation). The responses will be put into the single-point movement category if one finds the image of a figure point-by-point, and then connects them to get the image of the figure by using compass and straight edge only. Given two congruent figures, in order to know which transformation can transform or which transformation cannot transform one figure into the other figure, most students compare the orientation (facing) of the figures. Therefore, if one can tell correctly which transformation does and which transformation does not transform a given figure into another given figure in different situations, one will be classified in the category of identificaton of transformations. When one constructs a process by encapsulating a figure as a whole entity; applying the schema of single-point movement to it; decapsulating the image of the entity (the figure) as a process; and then drawing the image of it by coordinating with the process of identification, one will be placed in the category of figure movement.

It is very important for more than one coder to code the data in order to establish reliability. In this study, two coders put the subjects into categories. One coder was the researcher. The other was a person who had a masters degree in education and a baccalaureate degree in mathematics. It is reasonable to believe that the second coder had sufficient knowledge to put the subjects into categories using the operational definitions. After they finished the coding individually, they came together and discussed the differences in their coding.

Table 1. The Distribution of Subjects Possessing the Schema in Each Category (Level)

Subjects	(Level 0)	Definition (Level I)	Single-point (Level IIA)	Identification (Level IIB)	Figure (Level III)
S1	*				
S2	*				
S3		*			
S4		*			
S5		*			
S6		*			
S7		*	*		
S8		*	*		
S9		*	*	*	
S10		*	*	*	
S11		*	*	*	
S12		*	*		
S13		*		*	
S14		*		*	
S15		*		*	
S16		*	*	*	
S17		*			
S18		*			

*indicates the subject possessing the schema in that category (level).

Finally, they obtained an agreement about the coding, as shown in Table 1.

Based on the results in Table 1, our descriptions of the construction of the transformation schemata were divided into four levels which represented the students' understanding of the concepts. In Level 0, the students did not understand the concept. They either gave a wrong description of those transformations, or could not manipulate points in order to show what the action of flip, turn, or slide is. In Level I, they could give a description of the definition clearly, or there was evidence that they could show the subjects possessing the concept of the definition of transformations. But, they did not possess the single-point movement schema and the identification schema. Level II is comprised of two sublevels, which are IIA and IIB. In IIA, the subjects possessed only the single-point movement schema, which emphasized location of a transformation image. In IIB, the subjects possessed the complement, the schema of identification, which emphasized orientation (facing) of the transformation image. In Level III, the students had a completed structure of the transformation image, also known as the figure-movement schema. It emphasized both the location and the orientation (facing) of the transformation image.

1. Level 0

The earliest level at which this study can be conducted is, naturally, the one at which the student is judged by whether he or she can give the definition correctly and manipulate some points to show what the action of flip, turn, or slide is. In the excerpt, there is a subject, S1, who confused rotation with reflection. She used the word 'flip' to describe rotation when she was questioned about her understanding of rotation. Her response was as follows:

S1 Rotation is a flipping.

LAW Flipping?

S1 If you have this line here and something over there, you flip it when you want to rotate it. Then the image will be over here.

LAW Then how about reflection?

S1 I am confused.

LAW Do you know what a turn is?

S1 What is a turn?

LAW If I ask you to turn something . . .

S1 That's probably rotation. Reflection would be flipping.

LAW So, if you flip something, that is reflection.

If you turn something, that is rotation. Do you understand?

S1 Okay.

It is seen that the interviewer tried to lead her to clarify the difference between rotation and reflection, and she finally accepted it (Okay). But it is not reasonable, at this point, to conclude that S1 possesses the definition of rotation. Later, as shown in the following, the interviewer continues to ask her to find the rotation image of an object in order to test her previous response. She still gives the answer "you flip that over." Her actions to "flip that over" and "turn it over" indicate that she could not manipulate the points to show what a rotation (turn) is. It also indicates that she still possesses very little understanding even after the interviewer offers the correct statement. Therefore, it is reasonable to conclude from her responses that she did not possess the schema of definition of rotation. Note that S1 is still able to think in terms of moving any object around the plane resulting in it still being the same object (extended function schema) although she does not understand the concept entirely.

S1 I am not sure how to do it. I think you have to use tracing paper. You have to trace this (the object), and this (the angle). And then, you flip that over whatever and line it up with that.

LAW You mean after you trace the figure, then you flip it.

S1 Mm . . .

LAW Well . . .

S1 That you line up what you trace with this side right here. And whatever you line up, then you know that the image looks like. If you turn it over and line it up, then you will know what the image would be.

2. *Level I*

The students that are assigned to Level I are those who give the definition clearly, or show they possess the concept of the definition of transformations. Note that the subjects in Level I did not possess the single-point movement schema and the identification schema. In the excerpt, there is a student, S4, who is in Level I. S4 has the schema of manipulation of points. When that is coordinated with the extended function schema, an understanding of the definition of transformation is achieved. When she is asked about reflection, her responses are:

S4 Like a mirror. Reflection is a mirror image of the original.

LAW A mirror image of the original. Well, can you tell me any properties about reflection?

S4 If you put them on top of each other, they would be the same thing. I mean they would be identical. They would be no different.

LAW They can match each other exactly.

S4 Right.

Of course, it cannot be concluded that S4 is in Level I from such a general answer. The interviewer continues to ask her to find the flip image of a house to check her definition of mirror image. From her action of flipping the paper, it seems that she possesses the schema of manipulation of points. Moreover, her response, "and then copy it down," indicates that she coordinates the schema of manipulation of points with the extended function schema (flip the paper first, and then copy the figure) in her description of the definition of transformation.

S4 You would outline that house.

LAW How about the window?

S4 This window, you have to trace it, too.

LAW And then . . .

S4 You draw the line on the tracing paper, turn it (flip the paper), and then copy it down.

LAW Suppose I trace the house, the window, and this line. When I flip the tracing paper, maybe the house would go to here (I pretend to put the image higher than it should be).

S4 It would be down lower. It would be directly over here because it was a line diagonal.

3. *Level II*

There are two important components for making a transformation, the location and the orientation (facing) of the transformation image. Students have to be aware of these two components in order to understand the concept. These two components can be tested by the single-point movement (emphasizing location) and the identification of transformations (emphasizing orientation). Therefore, Level II is comprised of two sublevels, IIA and IIB. In IIA, the subjects possessed only the single-point movement schema. If one finds the images of a figure point-by-point and connects the points to get the image of the figure, the responses will be put into the single-point movement category. In IIB, the subjects possessed the complement, the schema of identification. In order to know which transformation can transform and which transformation cannot transform one figure into the other figure, most students compare the orientation (facing) of the figures when given two congruent figures. Therefore, if one can correctly tell which transformation does and which tranformation does not transform a given figure into another given figure in different situations, one will be in the category of identification of transformations.

In IIA, there is a student, S7, who has a good concept of single-point movement. When she is asked to find the reflectional image, her response is as follows. Note that she says "you do the same thing properly." It means that she will do the same thing for each point and connect them to get the image of the figure.

S7 We draw the perpendicular from the line; that will be the same distance from the points. Then, you do the same thing properly.
LAW You mention two things. One is perpendicular, and the other is same distance. Do you mean if you want to find the image of a point, then you need to draw a line passing through that point, and which is perpendicular to the reflectional line, and then measure the distance in order to get the image?
S7 Yes.

But when the interviewer asks S7 several questions concerning the schema of identification, her responses are an uncertain mixture of correct and incorrect answers. She relies heavily on the guidance of the interviewer. Although she does finally get all the answers correct, the procedure is capricious. Therefore, S7 is still considered to be in the single-point movement only.

In IIB, there is a student, S8, who does a good job in identification of transformation. But she does not possess the single-point movement schema. When she is asked to find out the translational image of a point, her response is connected to perpendicular, not parallel. And the statement is useless in finding the image. But she shows her strong ability to see which transformation can transform a figure into another figure and which transformation cannot. Since she has made a mistake at the beginning, she corrects it immediately without any help. Note that when she identifies a transformation, she always interiorizes the process of that transformation in her mind in order to support her answer. When she wants to reject a tranformation, she will compare the orientations (facings) of the original figure and the image figure of that transformation.

LAW Can you tell me something about this figure?
S8 Two letters 'Fs' or two polygons.
LAW Well, that's okay for two 'Fs' or polygons. Anything else?
S8 It looks like it is a rotation.
LAW It looks like a rotation.
S8 It is not a reflection. It could be a translation.
LAW Well. That means this figure . . .
S8 Oh! Not, it won't be rotation.' It is a translation.
LAW It is a translation. It is not a reflection. It is not a rotation.
S8 Right.
LAW Why do you say that it is a translation?
S8 If you have an arrow, and put it in this point and that point (two corresponding points), you will find that the arrows are the same.
LAW You mean if you connect two corresponding points and find the arrows, then all the arrows will be equal.
S8 Right. Yes.
LAW How about rotation? You say it is not a rotation.
S8 Not, it is not a rotation.
LAW Why? At the first time, you say it is a rotation, but you change immediately.
S8 Because if it was a rotation, then it is the center place, and the shape would turn.
LAW You mean if it is a rotation, the 'F' is not like this one. The facing will be different.
S8 Right.
LAW How about reflection?
S8 Well, it is not a reflection because if it were a reflection, this point would be here.
LAW Well, you should reflect 'F' in your mind to check the image in your mind and in the paper to see whether they are the same.

In summary, it can be said that the constructional order of single-point movement and identification is not linear, but parallel. It is confirmed by having students who only possess the single-point movement schema or the schema of identification. Moreover, there is no evidence to say which one comes first. But it seems that the concept of identification is a little bit easier than the concept of single-point movement (nine students possess schema of identification and six possess single-point movement schema). Of course, this statement needs further study.

4. Level III

In this level, the students had a completed structure of the transformation image, both in the location and the orientation. It is called the figure movement schema. It is when a subject constructs a process by encapsulating the figure as a whole entity; applying the schema of single-point movement to it; decapsulating the image of the entity (the figure) as a process; and then drawing the image of it by coordinating with the process of identification. One excerpt from the protocols is discussed.

The subject is S11, who really constructs a process by encapsulating the figure as a whole entity; applying the schema of single-point movement to it; decapsulating the image of the entity (the figure) as a process; and then drawing the image of it by coordinating with the process of identification. When S11 is asked to find the image, she shows that she possesses the single-point schema by saying, "Count down eight and over fourteen for each point of the square to get its image point. And then you connect those image points. That would be your square's image." Moreover, if we investigate her response ("Also, on the square, if you find out one image, like this one (an image point), you know that this is up two and over two (a process to draw a square), you can find that way too, can you?") carefully, we can see that she views a square as a whole entity; applies the schema of single-point movement to it (finds out one image); decapsulates the image of the entity as a process (up two and over two); and then draws the image of the square by coordinating with the process of identification. When the interviewer asks her which methods she would like to use, finding the other three points or tracing the square from the first image point, she prefers to find the other three points, "The first is easier for me to find out the image of the four points." The reason why the first method is easier is that it can be done by repeating the process of single-point movement. But the second method requires that we coordinate the process of single-point movement with the process of identification.

S11 You could count down one, two, three, ..., eight, and then over one, ... fourteen.

LAW Well, you count down eight, and then fourteen.

S11 Count down eight and over fourteen for each point of the square to get its image point.

LAW How many points are there? Each point, vertex, of the square. And then. . .

S11 Right. And then you connect those image points. That would be your square's image. And then you can do the same thing for each vertex over here.

LAW You mean this polygon.

S11 Yeah, the polygon there.

LAW Okay, I will repeat once. You translate the vertices of the square, four vertices of the square individually, and then connect the image points, and then you do it the same for the polygon here.

S11 Right. Also, on the square, if you find out one image, like this one (an image point), you know that this is up two and over two (a process to draw a square), you can find that way too, can you?

LAW Yeah.

S11 After you find one, you can. . .

LAW That means you find the image of one point. Then, because you know that this one is a square, you trace the square up two, over two, down two, and then right two.

S11 Right.

LAW It is good. But, you are using the method of dot paper. If I asked you to find out the image by using compass and straight edge only, how can you find out the answer?

S11 I forgot the answer. You can measure the distance between these two. . .

LAW You measure the distance between one of the endpoints of the (translation) arrow to one of the vertices of the square.

S11 And you measure over right here, and then you take from this point, from the vertex, you measure the distance of the arrow over here. . .

LAW Wait a minute, can you repeat once more when you measure from this vertex.

S11 You measure the distance from here (one of the endpoints of the arrow) to here (one of the vertices of the square).

LAW You measure the distance between the endpoint of the arrow to the vertex, and then. . .

S11 And then you mark off.

LAW Use this distance to mark off somewhere.

S11 Over here, I guess. And then you measure from there to the distance here and mark off there. Is it right?

LAW Well, . . .

S11 Maybe it is from here. You measure the distance between these two and mark it off.

LAW Well, you measure the distance from the endpoint of the arrow to one vertex.

S11 Right.

LAW Then you mark some points at where?

S11 That's where I am confused. Do you take it on here and mark it?

LAW You change the position to another endpoint of the arrow and mark the same distance.

S11 Right.

LAW Then. . .

S11 And then you measure this distance (the length of the arrow) and mark off on here that distance. Is it right?

LAW Well, I will repeat what you are doing. You measure the distance from one endpoint of the arrow to one vertex of the square, and then you move your compass to the another endpoint of the arrow and mark the same distance. Next, you measure the length of the arrow, and then you put the compass at the vertex of the square and mark another arc. The intersection point of the two arcs is the (image of the) vertex of the square. That's correct.

S11 Mm. . .

LAW Now you get the image point of one vertex. Then, you can do it for the other three vertices or trace the square which depends on the first image point. Okay.

S11 Okay.

LAW Which methods you would like to use, finding the other three points or tracing the square from the first image point?

S11 The first is easier for me to find out the image of the four points.

LAW You mean it is easy for you to find the four image points individually, and then connect them. Do you do the same thing for this polygon?

S11 Mm. . .

IV. Discussion

The genetic decomposition of geometric transformations discussed below depends entirely on Dubinsky's general theory, my understanding of the concept, and the protocols of the interviews. The most important information obtained from the protocols was the many explicit examples of the forms of reflective abstraction, which provide the basis for our derivation of the genetic decomposition of the geometric transformations.

1. Genetic decomposition

In the beginning, there are points (or figures) in the plane which are the objects, and the actions on the objects, such as: connecting two points with a line, measuring the distance between two points (the length of a line segment), copying a distance from a given point on a line to another point on that line, measuring an angle, copying an angle, drawing a line through a given point and parallel to a given line, drawing a line through a given point and perpendicular to a given line, moving a figure in a certain direction and distance, turning a figure in some angle at a point, and flipping a figure along a line. This is the schema (manipulation of points) that I assume the student possesses. Furthermore, I assume the student has a schema for functions that transforms numbers into other numbers.

The genetic decomposition of the geometric transformations is illustrated in Figure 1. According to the protocols, the first step is to learn the mental actions of the schema of manipulation of points into processes. Those mental actions must be learned to form mental processes in order to facilitate mental constructions. And then, a new set of processes can be constructed by coordinating these learned processes. For example, students can coordinate the learned process

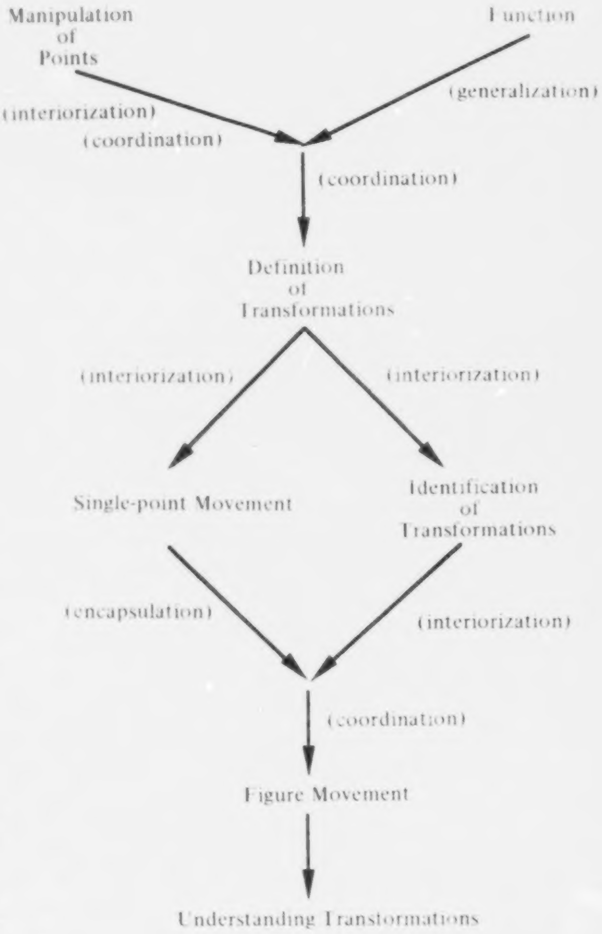
Manipulation
of
Points
Function
(interiorization)
(coordination)
(generalization)
(coordination)
Definition
of
Transformations
(interiorization)
(interiorization)
Single-point Movement
Identification
of
Transformations
(encapsulation)
(interiorization)
(coordination)
Figure Movement
Understanding Transformations

Fig. 1. Genetic decomposition of geometric transformations

of drawing a parallel line with that of measuring the distance to form a new process. That consists of drawing a line through a given point and parallel to a particular line; generating a result; and then measuring a certain distance from that point in a certain direction on that result.

The second step is to generalize the function schema in order to include processes that transform points into points in the manner of one-to-one correspondence. Of course, I do not expect that preservice elementary school teachers, will be aware of the extended function schema in this terminology. What I expect is that the student will be able to think in terms of moving any object (or any point) around the plane, and the result being still the same object (or point). The students need to coordinate this extended function schema with those coordinated processes of the schema of manipulation of points to form new processes. And they must learn the new process in order to obtain the definition of the tranformations.

The two important components for making a transformation are the location and the orientation of the transformation image. Students have to be aware of these two components in order to understand the concept. These two components can be developed from the single-point movement (emphasizing location) and the identification of transformations (emphasizing orientation). After the schema of definition of transformation has been constructed, the student is ready to move on to the construction of these two schemas. It is indicated in Figure 1 that these two schemas are developed in parallel.

The objects of the schema of identification of transformations are figures in the plane. Once the student has constructed the definition schema, he or she can learn the processes to construct the schema of identification of transformations. Given two congruent figures, one may learn the process of that transformation to produce the image of it in order to know which transformation can and which transformation cannot transform one figure into the other figure. If the result matches the other figure in orientation, then one may conclude that it is the desired transformation. If the result does not match the other figure in orientation, then one may conclude that it is not the desired transformation. When this has been learned, one has constructed one of the main branches of the concept of the geometric transformations.

The objects of single-point movement schema are those individual points in the plane. One applies an action to a point, and then gets its image. For example, when one tries to find the reflectional image of a point "A", one needs to construct the process of drawing a line passing through the point and perpendicular to the reflectional line; measure the distance from the point to the reflectional line; and construct another point "A′" on the perpendicular line so that it is the same distance as point "A". At this point, there has been a major step in learning. Also, when this has been learned, one has constructed one of the other main branches of the concept of geometric transformations.

Furthermore, if one views any figure as a process of drawing that figure, then one can encapsulate the process to form a new object. Now, when one assimilates these new objects to the single-point movement schema as an element, and accommodates this single-point movement schema to form a higher level schema, one has constructed the figure movement schema.

There are two differences between the single-point movement schema and the figure movement schema. The first difference is their objects. One is a point and the anothen is a figure. The second is the steps that one will follow to solve a problem. For example, a question is asked to find the transformation image of a square. One who only has the single-point movement schema will construct the process by finding the images of the vertices of the square one by one and connecting them to get the image of the square. If one possesses the figure movement schema, one will construct a process by encapsulating the square as a whole entity; applying the schema of single-point movement to it; decapsulating the image of the entity (the square) as a process; and then drawing the image of it by coordinating with the process of identification, which determines the orientation of the image.

Finally, the student is ready to put all of the schemata together and construct the concept of geometric transformations. Since the student has just acquired the concept, it may not be firmly established. Examples and exercises using this concept to assimilate disequilibrating elements are necessary at this point. After iterating these processes for different questions, not only does one possess a stabilized concept and a wider class of examples, but also one can conclude that, for two particular congruent figures, only one of the three transformations can transform one figure to the other.

In the meantime, I would like to list the most important mental constructions in the genetic decomposition that the student needs to learn in order to acquire the concept of geometric transformations.

Construction 1	Interiorize the actions of the schema of manipulation of points into processes.

Construction 2	Coordinate two or more processes of the schema of manipulation of points to form a new process.
Construction 3	Generalize the schema of function to include processes that transform points into points.
Construction 4	Coordinate those new processes of the schema of manipulation of points with the processes of the extended function schema.
Construction 5	Interiorize the processes of the schema of definition to construct the schema of identification of transformations.
Construction 6	Interiorize an action that acts on a point to get its image.
Construction 7	Encapsulate the process of drawing a figure to obtain a new object, and assimilate this object to single-point movement.
Construction 8	Coordinate the processes of single-point movement with identification of transformation.

It is believed that the above series of reflective abstractions could be used to construct the concept of geometric transformation. Also, the genetic decomposition illustrated here is not necessarily the only way to decompose this concept. It is based on Dubinsky's general theory, my understanding of the concept, and the protocols of the interviews.

V. Conclusion

There are many reasons why students feel mathematics is one of the least acquired and most difficult subjects at all levels from elementary school up to graduate school. One of the most important reasons, I believe, is that most mathematics teachers are not concerned about the necessity of constructing mathematics concepts in their students' minds when they design their instruction.

With the genetic decomposition of a particular mathematics concept, it is possible to see how a student can learn. And it shows an explicit description of possible construction processes between schemata of that concept. Therefore, as mathematics teachers, we can use the results to design instructions that can help students follow the construction processes in the genetic decomposition and make certain reflective abstractions.

Someone may ask how to use the results to design instructions that can help students learn the concept. Dubinsky suggests that using a powerful computer language and assigning students various computer tasks can help students engage in the activities that seem to lead to the construction which their teachers want them to make. For getting the students to move along the path specified by the genetic decomposition of geometric transformation, it is believed that the programming language Logo could be effective.

1. An example of an instructional treatment design

The goal of designing instructional treatment based on genetic decomposition is to move students from one position on the chart (in figure 1) to another position. An example of an instructional treatment design is outlined which consists of computer experiences designed to stimulate the students to perform the reflective abstractions to construct the required schemata that make up the genetic decomposition of geometric transformations.

Our instructional treatment first considers the mental construction which interiorizes the actions of schema of manipulation of points into processes. Referring to figure 1, it is assumed that students have the antecedent schema of manipulation of points. Therefore, we try to induce students to do this by asking them to write LOGO procedures that will perform the actions. Here is an example of a procedure (let us call it CONNECTPOINT) which connects two points [3 5] and [12 14] by a line segment:

```
TO CONNECTPOINT
PENUP
SETPOS [3 5]
PENDOWN
SETPOS [12 14]
END
```

The LOGO command PENUP tells the turtle not to draw on the screen, and the command PENDOWN does the reverse. The command SETPOS [3 5] tells the turtle to go to the rectangular coordinates [3 5]. The result is that a line segment appears on the screen which connects the points [3 5] and [12 14]. We may see that students who write such procedures may have learned the corresponding actions. And students need to do all the actions in the schema with different pairs of points before getting to the next step.

The next step is to coordinate two or more processes of the schema of manipulation of points to form a new process. It helps to ask students to write LOGO procedures that combine two or more processes of the schema of manipulation of points. Here is an example of a procedure (let us call it POINTLENGTH) which will draw a line segment satisfying:

(1) One endpoint is at [35 67].
(2) It is parallel to a line 60 degrees (clockwise) from a vertical line.
(3) Its length is 150 turtle steps.

```
TO POINTLENGTH
PENUP
SETPOS [35 67]
PENDOWN
RIGHT 60
FORWARD 150
END
```

In the LOGO environment, the original direction of the turtle is north. In order to draw a line segment which is parallel to a line 60 degrees (clockwise) from a vertical line, we simply use the command RIGHT 60. The procedure POINTLENGTH links three processes (the process of going to the point [35 67], the process of turning 60 degrees clockwise, and the process of drawing a line segment with length 150 turtle steps) together. Working with this task helps students coordinate the processes to form a new process.

The third construction is to generalize the schema of function to include processes that transform points into points. As mentioned above, we may see that students are able to think in terms of moving any object around the plane and the result being still the same object. Therefore, we consider helping students coordinate those new processes of the schema of manipulation of points with the processes of the extended function schema. The computer task in this step is to have students use their procedures (written in the previous steps) to form new procedures by introducing variables to their procedures. For example, they can introduce variables to the procedure CONNECTPOINT such as:

```
TO CONNECTPOINT : A : B
PENUP
SETPOS : A
PENDOWN
SETPOS : B
END
```

Here A, B are the variables which are in the form of tuple (like [3 5]). Students will be encouraged to use different points as input in order to study the behavior of the procedure. This can help them to construct the connection in their minds. At this point, it can be seen that students are ready to construct the schema of the definition of transformations. Now, it is time to give a general description of the definition of the three transformations. Of course, it is assumed now that the students will have more sense about what the transformations are, and they are capable of thinking about those transformations concretely as mental processes.

Another task concerns the schema of identification of transformations. The main construction is to learn the processes of the schema of definition to construct the schema of identification of transformations. In the analysis, it can be seen that if a student wants to know which transformation can and which cannot transform one figure into the other figure, the student may compare the orientation (facing) of the figures. Therefore, students will be asked to write a procedure which draws a geometric figure. Next students will be asked to add a LOGO command RIGHT 20 (or any integer) at the beginning of their procedures and predict the orientation of their figures. Also they will be asked to change all the LOGO commands FORWARD (RIGHT) to BACKWARD (LEFT) and predict the orientation of their figures. These activities can help the students become aware of the fact that the change of heading of the turtle changes the orientation of the figure. It provides a general technique of having students learn changed process and compare the figures of original process and changed process.

The next set of activities concerns the schema of single-point movement. In order to facilitate the construction of learning an action on a point to get its image, it is necessary for the student to understand the definition of the transformations, and to be able to learn the actions specified by the definition. Therefore, the students will be asked to write procedures that can transform a point to its image under a given transformation. Then, the students will also be asked to write procedures that can transform various points on the plane to their images under the given transformation. An example of a procedure which can produce the translational image of a point is:

```
TO TRANSLATION : POINT : DIRECTION
      : DISTANCE
PENUP
SETPOS : POINT
RIGHT : DIRECTION
FORWARD : DISTANCE
MAKE "IMAGE POS
SETPOS [100-130]
ASK MYWINDOW [PRINT : IMAGE]
END
```

The LOGO command MAKE "IMAGE POS tells the turtle to put the rectangular coordinate of its present position into the variable named IMAGE. And the

LOGO command ASK MYWINDOW [PRINT: IMAGE] asks the turtle to print the value of the variable IMAGE on the screen at its present position. The result is that the rectangular coordination of the image appears on the screen at the point [100-130]. This set of activities will cover all three kinds of transformations which are being studied. Moreover, students have to run the procedures with different points in order to enhance the necessary constructions.

The next construction is to encapsulate the process of drawing a figure to obtain a new object. This encapsulation is well developed since people always see a geometric figure as an object. At the same time, if students view any geometric figure as a process of drawing that figure, any figure can be seen both as a mental process and as a mental object. This can be done by asking students to draw geometric figures. For example, one who wants to draw a squre can write a LOGO procedure SQUARE as follows:

```
TO SQUARE
REPEAT 4 [FORWARD 100 RIGHT 90]
END
```

One who recognizes this sequence of processes as a new object SQUARE can induce encapsulation. Indeed, most geometrical figures are 'objects' in the physical sense. The difficulty is to accommodate the schema of single-point movement into the schema of figure movement after the assimilation of the mental object successes. It is observed that, after a student encapsulates a process (a figure) as an object and assimilates it into the single-point movement, he or she performs a transformation of the object without accommodating it into the schema of figure movement. As a result, the location of the image is correct, but there is an error in the orientation of the image.

The problem is, in terms of Logo language, that the student is not aware of the heading of the turtle, which may change if the position of the turtle changes. In order to facilitate this level of construction, it is extremely helpful to make students aware of this cognitive conflict. Therefore, students will be asked to modify their procedures in the single-point movement so that the new programs can perform a figure at a time. And then, a well-chosen transformation and a figure, such as a reflection with diagonal reflectional line and a HOUSE, will be used to help students become aware that the heading of the turtle will change if the position of the turtle changes.

At this point, students are ready to put all of the schemata together and construct the concept of geometric transformation. Since the students have initially acquired the concept, examples and exercises using this concept to assimilate disequilibrating elements are necessary. After iterating these processes for different questions, not only does one possess a stabilized concept and a wider class of examples, but also one can conclude that, for two particular congruent figures, only one of the three transformations can transform one figure to the other.

As has been seen, the instructional treatment is designed to move the students along the path specified by the genetic decomposition of geometric transformation. These activities, I believe, can help to induce the mental constructions that the student needs in order to acquire the concept of geometric transformations. After the instructional treatment, all the procedures that the student has written can serve as a tool to help him or her in solving problems. Of course, it is not the main concern of the activities, which is to help students to construct the necessary reflective abstractions of geometric transformations.

In conclusion, I have provided a description of possible instructional treatments. I think at this point it is good to quote a statement from Dubinsky: "Now, the researcher's new understanding of what it means to learn this particular topic is used to redesign the instructional treatment and the entire activity is repeated, perhaps at a later time with a different class. The iterations continue as long as desired to hopefully coverage on a better understanding of the student's construction of this particular topic and how instruction can help her or him make that construction. In particular, it is also expected that the effect of the instructional treatment on student learning improves as the paradigm is iterated."

References

Ayres, T., Davis G., Dubinsky E., & Lewin, P. (in press). Compute experiences in learning composition of functions. *The Journal for Research in Mathematics Education.*

Burger, W.F. (1982). Graph paper geometry. In L. Silvey, & J.R. Smart (Eds.), *Mathematics for the middle grades (5-9)* (pp. 102-117). Reston, Va: The National Council of Teachers of Mathematics.

Clements, D.H., & Batista, M.T. (1989). Learning of geometric concepts in a Logo environment. *Journal for Research in Mathematics Education, 20,* 450-467.

Craine, T.V. (1985). Integrating geometry into the secondary mathematics curriculum. In Hirsch, C.R., & Zweng, M.J. (Eds.), *The secondary school mathematics curriculum* (pp. 119-133). Reston, Va: The National council of Teachers of Mathematics.

Dubinsky, E. (1986). Teaching mathematical induction I. *The Journal of Mathematical Behavior, 5,* 305-317.

Dubinsky, E. (1991a). Reflective abstraction in advanced mathematical thinking. In Tall, D. (Ed.), *Advanced Mathematical Thinking*. London: Riedel

Dubinsky, E. (1991b). The constructive aspects of reflective abstraction in advanced mathematics. In Steffe, L.P. (Ed.), *Epistemological foundations on mathematical experiences*. New York: Springer Verleg.

Dubinsky, E. (draft). How Piaget's and related work should influence K-12 curriculum design.

Dubinsky, E., Elterman, F., & Gong C. (1988). The student's construction of quantification. *For the Learning of Mathematics, 8*, 44-51.

Dubinsky, E., & Lewin, P. (1986). Reflective abstractive and mathematics education: The genetic decomposition of induction and compactness. *The Journal of Mathematical Behavior, 5*, 55-92.

Ernest, P. (1988). Using microcomputers with 15 year olds to retrain transformation geometry skills. *International Journal of Mathematical Education in Science and Technology, 19*, 269-279.

Hoffer, A. (1981). Geometry is more than proof. *Mathematics Teacher, 74*, 11-18.

Kerlinger, F.N. (1986). *Foundations of behavioral research* (3rd ed.). New York: Holt, Rinehart and Winston, Inc.

Kidder, F.R. (1976). Elementary and middle school children's comprehension of Euclidean transformations. *Journal for Research in Mathematics Education, 7*, 40-52.

MacPherson, E.D. (1985). The themes of geometry: Design of the nonformal geometry curriculum. In Hirsch, C.R., & Zweng, M.J. (Eds.), *The secondary school mathematics curriculum* (pp. 65-80). Reston, Va: The National Council of Teachers of Mathematics.

Mayberry, J. (1983). The van Hiele levels of geometric thought in undergraduate preservice teachers. *Journal for Research in Mathematics Education, 14*, 58-69.

McDonald, J.L. (1989). Cognitive development and the structuring of geometric content. *Journal for Research in Mothematics Education; 20*, 76-94.

Noss, R. (1987). Children's learning of geometrical concepts through Logo. *Journal for Research in Mathematics Education, 18*, 343-362.

Papert, S. (1980). *Minstorms: Children, computers, and powerful ideas*. New York: Basic Book.

Piaget, J., Grize. J., Szeminska, A., & Bang, V. (1977). The coordination of pairs. In J. Hintikka (Ed.), *Epistemology and psychology of function*. (F.X. Castellanos, & V.D. Anderson, Trans.). Chicago: University of Chicago (Original work published 1975).

Schultz, K.A., & Austin, J.D. (1983). Directional effects in transformation tasks. *Journal for Research in Mathematics Education, 14*, 95-101.

Sherard III, W.H. (1981). Why is geometry a basic skill? *Mathematics Teacher, 74*, 19-21.

Thompson, P. (1985). A Piagetian approach to transformation geometry via microworlds. *Mathematics Teacher, 78*, 465-471.

Williford, H.J. (1972). A study of transformational geometry instruction in the primary grades. *Journal for Research in Mathematics Education, 3*, 260-271.

幾何變換之基因分解使用
LOGO程式語言設計教學情境範例

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摘　要

本研究嘗試探討幾何變換概念的認知發展過程，研究方法及步驟根據Dubinsky教授所提倡的理論，而問題的設計則採用van Hiele的幾何層次學說。18位小學師範生爲本研究的研究對象。根據面談結果顯示，幾何變換概念可分爲四種不同的認知發展層次。透過Dubinsky教授的理論，本研究對此認知發展層次建立了幾何變換概念的基因分解。從所建立的基因分解中，本研究使用LOGO程式語言設計了一些教學情境範例，藉以刺激並幫助學生建立學習及理解幾何變換概念所需的反射抽象。

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Conceptual Development of Space and Time of Children

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ABSTRACT

The study focused on understanding the present conditions of the conceptual developments of time and space of the students in our country. The populations of this study were the students from the third grade of primary schools up to the second grade of junior high schools among the eight cities and counties in southern Taiwan. We used the method of group sampling choosing randomly two percent of students to get a total amount of 7122 samples.

The method of data collection herein adopted the method of Demonstration-lead-to-prediction test that, hereafter, was abbreviated as DLPT.

We developed a rating tool. Its validity of the range of conceptual contents and the group stability of the samples were tested by evaluating the specialist's validity, constructs validity, and test-retest stability.

It was found that: (1) the development of the concept of time and space of students in our country was getting more comprehensive as their ages increased; (2) students' science conceptual maturity score (CMS) (Hung, 1991) was also increasing with their ages; (3) time and space concepts could be classified into five conceptual development stages; (4) time schedule for teaching the concepts of time and space had been suggested; (5) the norm of CMS was of normal distribution; (6) the time and space coneptual developments of students in each grade had something to do with students' backgrounds (such as the occupation and the education of their parents, the living regions, and student's CMS, etc.).

Key words: time and space, conceptual development, cognitive development, norm

I. Introduction

According to the theory of learning that was proposed by the psychologist Piaget, the cognitive development of each person is progressing stage by stage. Piaget (1952) inferred that all cognitive activities of mankind are the activities of organization and adaptation they did for consciousness circumstances. For the purpose of explaining this fact, he created four psychology concepts: schemata, assimilation, accommodation, and equilibrium. The four cognitive stages considered by Piaget (1963), in proper sequence, were sensori-motor stage, pre-operational stage, concrete operational stage, and formal operational stage. Normally, the process of development of everyone follows these four stages. However, the speeds of development are often different in different kinds of persons as a result of their various natural endowments and experiences. There are four major elements, proposed by Piaget (1969), that affect the cognitive developments: maturation, physical experience, social interaction, and equilibration. Every one of these elements has all the necessary conditions of cognitive development. None of them can promote the cognitive development alone, but they are able to promote together.

Bruner's (1969) view about the children's cognitive development was almost the same as Piaget. He furthermore thought there are three ways for the children to recognize external events. These are: (1) the enactive representation, this being equivalent to the sensori-motor stage of Piaget, (2) the ikonic representation, this being equivalent to the concrete operational stage of Piaget, and (3) the symbolic representation, this being similar to the formal operational stage of Piaget. On the contrary, Bruner thought that the intelligence development of children is not always limited by their age. It was this way of reasoning that was of a different view from Piaget.

However, there is another famous psychologist, Ausubel (1968), who proposed an idea of advance organizer in his theory of learning. He considered that the most important single factor of influence is what the learner already knows. Therefore, when a teacher is going to teach a certain concept, he should know in advance what knowledge concerning this concept his students already know.

From a new cognitive point of view, which is based on the theory of knowledge of Piaget's cognitive development and Ausubel's meaningful learning theory, many researchers (Linn, 1987; Guo, 1988, 1990) now have formed gradually an unanimous agreement about the student's learning of natural science in the following ways, such as, student's original knowledge acting as an important role in the learning process, and learning is the changing of concept, etc. In the new idea concerning cognition, the questions concern how to investigate the cognitive structures that students already have, and how to understand their special features. With this a teacher can give them appropriate help easily in order to accomplish a conceptual change of students' knowledge; this can become a new direction for the teachers to improve their teaching techniques in natural science.

To this end, the objective of this study was to investigate the students' conceptual development state of time and space first, and then what they already knew about these concepts in different ages. From the above mentioned theories, we have made the following assumptions: (1) students' conceptual developments are growing with their age, (2) student's conceptual developments have something to do with their environment such as education and occupation of their parents, living regions, and CMS, etc.

In this paper, we shall present the following work of this study: (1) Establishing a rating scale for the conceptual development of time and space, (2) Establishing a norm of time and space conceptual development of the students in our country, and (3) Analyzing the relationships among the students' time and space conceptual development and the backgrounds of students' environments.

II. Methods

1. Sample selection

Here, the populations are the students from the third grade of primary school up to second grade of junior middle school (the eighth grade) among the eight counties and cities in southern Taiwan. We use the method of group sampling, by considering the factors of students' sex (half male and half female), social and economic level, cultural backgrounds (such as commercial, industrial, agricultural, and fishing zones), etc., as chosen randomly from two percent of students to get a total amount of 7122 samples.

2. Development of instrument

The instrument used by this study is a rating scale including 20 items concerning time and space concepts. We first set the range of the contents of this scale by taking the following materials as reference: (1) currently-used textbooks such as Physics and Chemistry in the junior middle schools and Natural Science in primary schools. (2) Papers and books (Bar, 1989; Clement, 1982; Piaget, 1971) concerning the concepts of time and space, and (3) opinions from experts such as experienced teachers and professors who have taught physics for many years. From these contents, we then set 20 items as the rating scale. Finally, we tested their validity and stability by using the following methods:

(1) Validity

A. Content and face validity: We gave several examinations with this rating scale to the students in each grade. Then we revised the expressions of the items according to the results of the examinations. After this, we discussed these items with physics professors in National Sun Yat-sen University and National Kaohsiung Normal University to further revise the items until they are in agreement with the opinions in the discussion.

B. Construct validity: After we gave examinations to the whole sample of students, and from the results of these examinations, we chose those items indicating that the average scores of the students are increasing as the student's grade increased, to be the proper items for determining the conceptual development.

(2) Reliability

The test-retest reliability was evaluated by giving a pretest and posttest to the same group of students.

3. Examiner's training

Data collection of this study adopted the method of DLPT (Hung, 1991). Before using this method, the examiners must receive an examination conducting training in advance.

4. Data collection

After we finished the testing for validity and stability, and the examiner's training, we chose the period of time after the first monthly test, and went to every sample school at separate times to collect data.

5. Data analysis

We keyed in the following data into PC: students' backgrounds, items chosen by students from the multiple-choice questions in rating scale, and CMS.

(1) Validity evaluation of the rating scale

A. We evaluated the Pearson's correlation coefficient from the results of pretest and posttest.
B. We evaluated the *t* test value from the student's score from the results of pretest and posttest.
C. We evaluated chi-square test between the numbers of students who had chosen the correct answer in each item both in pretest and posttest.

(2) Statistical treatment of the large sample data

A. Analyze the developing tendency of the percentage number of students with correct answers in each item in each grade and in each CMS level by evaluating the F test.
B. Analyze the relationship between students' backgrounds and theirs answers in each item by evaluating chi-square test.

III. Results

1. Instruments

After we evaluated the items in the rating scale following the procedure described above, we collected twenty of them that were fit for judging conceptual development, to be the rating tools of this study as shown in the Appendix. The basic concepts of time and space we considered are listed in Table 1. With this rating tool, we gave a pretest and posttest, in a period of two weeks, to two classes of students both of the third grade and the eighth grade. Then we inspected the group stability of those items in rating scale by evaluating the Pearson's correlation coefficient, as well as the chi-square test and *t* test values between the pretest and posttest. The results of trend analysis are shown in Table 2 and Table 3.

2. Establish norms

We would consider the items in the rating scale that had passed the tests on validity, stability, and especially on the construct validity as a rating tool for establishing norms. There were altogether 15 items of this kind. In this study we established two norms: students' CMS percentile rank norm and students' time and space conceptual development norm.

(1) CMS percentile rank norm: We established these norms shown in Table 5 by evaluating the CMS percentile ranks of sample students.
(2) Time and space conceptual development norm: We established these norms as shown in Table 6 by evaluating the achievement scores of both the sample students in each grade and all sample students from these items.

3. Variance analysis between the conceptual development and the student's background

From the statistical analysis of evaluating the F test and chi-square test, we found that there were six factors of students' backgrounds having something to do with students' conceptual achievement. These six factors are fathers' occupations, mothers' occupations, fathers' level of education, mothers' level of

Table 1. The Basic Concepts of Time and Space

Basic concepts of time	Basic concepts of space
Period of time	Length
Sequence of time	Area
Simultaneous	Volume
Periodic	Direction
Method of recording time	Magnitude
	Shape

Table 2. The Percentage Number of Students in Each Grade with Correct Answers in Each Questions

Item number	Number of grade							F value
	3	4	5	6	7	8	Total	
1	57.8	54.6	61.0	68.3	69.2	@75.2	64.8	33.29*
2	53.4	63.7	68.4	67.4	@74.0	78.5	68.1	37.09*
3	58.6	59.4	63.0	58.5	68.0	@78.1	64.7	9.00*
4	19.0	23.2	35.6	35.9	46.4	66.6	38.8	40.47*
5	56.7	@75.0	87.8	85.4	85.7	90.7	80.8	10.03*
6	21.9	26.4	53.4	44.0	47.8	60.0	43.0	12.95*
7	@72.5	78,6	85.5	82.1	83.6	87.8	81.9	14.09*
8	50.1	@78.1	82.6	86.2	87.5	88.7	79.5	8.32*
9.1	@72.1	80.2	78.4	84.1	83.1	89.9	81.6	23.05*
9.2	56.7	@73.5	73.3	74.2	77.5	83.5	73.5	11.91*
10	32.4	40.1	42.9	44.8	48.9	57.4	44.9	81.97*
11	5.2	9.3	20.4	25.7	49.2	67.3	30.9	56.09*
12	61.3	@70.7	72.2	72.6	75.9	82.2	72.8	29.52*
13.1	69.2	68.7	@73.1	76.9	74.0	79.1	73.7	17.57*
13.2	57.0	69.6	@72.5	74.1	74.0	76.2	70.9	9.73*
13.3	57.5	60.9	64.1	68.4	67.0	@71.8	65.2	63.86*
13.4	53.9	59.6	63.0	66.5	64.0	@72.8	63.6	23.88*
14.1	39.2	47.3	64.8	@76.1	81.0	89.6	67.4	136.47*
14.2	62.5	64.5	@75.5	77.9	81.8	87.8	75.6	139.71*
14.3	67.1	@73.9	81.7	86.4	87.3	93.6	82.2	87.44*

Table 3. The Percentage Number of Students in Each CMS Level with Correct Answers in Each Questions

Item number	Order of CMS level							F value
	1	2	3	4	5	6	Total	
1	37.5	58.7	63.9	68.7	@73.9	90.4	64.8	41.43*
2	50.0	68.9	66.9	@73.5	84.4	88.5	68.1	33.52*
3	37.5	58.1	63.5	69.2	@79.4	86.5	64.7	41.52*
4	20.8	28.1	36.3	45.5	68.3	@86.5	38.8	86.48*
5	62.5	@70.5	80.1	86.1	95.0	98.1	80.8	41.16*
6	29.2	34.0	41.5	47.7	64.8	@90.4	43.0	64.52*
7	62.5	@74.1	82.0	85.2	91.0	94.2	81.9	29.22*
8	47.9	@70.3	78.9	84.9	89.5	94.2	79.5	51.45*
9.1	@72.9	74.5	81.0	85.8	87.4	96.2	81.6	16.27*
9.2	41.7	65.2	@72.7	78.7	86.4	88.5	73.5	45.47*
10	37.5	37.5	44.0	48.5	56.8	@82.7	44.9	32.14*
11	29.2	17.0	28.5	38.2	67.2	@78.9	30.9	78.22*
12	41.7	61.6	@72.6	78.4	83.9	90.4	72.8	48.78*
13.1	64.6	69.9	@72.9	76.4	82.4	84.6	73.7	9.75*
13.2	52.1	62.4	@70.5	74.9	83.4	80.8	70.9	20.58*
13.3	35.4	57.4	64.4	@70.1	76.4	76.9	65.2	30.74*
13.4	35.4	55.7	63.7	67.1	@72.9	73.1	63.6	24.37*
14.1	41.7	50.8	65.8	@76.9	90.5	94.2	67.4	69.24*
14.2	54.2	64.2	@75.0	81.1	91.0	92.3	75.6	40.12*
14.3	64.6	@72.4	81.9	86.6	96.5	94.2	82.2	33.34*

Table 4. The Categories of Conceptual Stage, CMS Level, and the Suggested Grade for Teaching of Each Item in Rating Scale

Percentage number of student	Item number of rating scale	Stage number	Level number of CMS	Suggested grade for teaching
82.2	14.3	1	2	2
81.9	7		2	2
81.6	9.1		1	2
80.8	5		2	3
79.5	8		2	3
75.6	14.2	2	3	4
73.7	13.1			
73.5	9.2			
72.8	12			
70.9	13.2			
68.1	2	3	4	5
67.4	14.1			5
65.1	13.3			6
64.8	1		5	6
64.7	3			7
63.6	13.4			7
44.9	10	4	6	8
43.0	6			
38.8	4	5		
30.9	11			

education, living regions, and students' CMS. Statistical analysis results of students' average concepts achievement scores with respect to these six factors are listed in Table 7.

IV. Discussion

From the results of pretest and posttest, we found that all the items except No. 13.1 had good stability. From the results of trend analyses shown in Table 2 and Table 3, we can see that the percentage number of students with correct answers in each item increased when both their grade number and CMS level were increasing. Therefore, it can be sure, by these facts, that the construct validities of the rating scale were good.

When we rank successively the total percentage number of students with the correct answer in each item in the order from the highest to the lowest, we found they could be divided into five stages as shown in Table 4. We chose for each item the CMS level, with the percentage number the first time reaching up to 70, to be the CMS level that item belongs to, we classified the twenty items into six CMS levels as shown in Table 4. We found that the classification of the 20 items into these five stages and the six CMS levels matched very well. Therefore, we took these five stages as the five conceptual development stages of space and time. The concepts of space and time in each of these five stages are listed in Table 4.

The distinctive features of the concepts in each stage are described as follows:

Stage 1

The concepts in this stage are concrete, frequently used, and can be understood without concerning other concepts, such as

(1) the left and right direction (item 9.1)
conservation of area and volume (item 5 and 7)
capacity of a fixed space (item 8)
tracing backward the changing of seasons; (item 14.3).

Stage 2

The distinctive features in this stage are as follows:

1. the concepts that children had experienced, but not frequently used, such as:
   (1) east and west directions (item 9.2)
   tracing forward the changing of seasons (item 14.2);
2. the concept of comparison with the time order of an interlock events, such as the concept in item 12;
3. Concepts that have connection with other concepts, for instance, time concept connecting with velocity and space, and the concept about the judging of the order of precedence in items 13.1 and 13.2.

Stage 3

The distinctive features in this stage are as follows:

1. concepts that have connection with other concepts and experience, such as:
   (1) to judge the period of time in a race (items 13.3 and 13.4)
   (2) length concept connecting with other experiences, such as its being easier to walk down hill than walk up hill, etc. (items 1, 2, and 3);
2. a concept that is different from the custom (item 14.1).

Stage 4

The distinctive features in this stage are as follows:

1. volume of different formative spaces (item 6)
2. the real direction in a mirror symmetry space (item 10).

Table 5. CMS Percentile Ranks of Sample Students

CMS	3rd grade			4th grade			5th grade			6th grade		
	A	B	C	A	B	C	A	B	C	A	B	C
600										99.8	4	1,162
583										99.6	2	1,158
567										99.4	0	
550										99.4	2	1,156
533										99.3	0	
517				99.9	1	1,114				99.3	1	1,154
500				99.9	1	1,113	99.9	2	1,178	98.9	8	1,153
483				99.8	0		99.8	1	1,176	98.2	8	1,145
467				99.8	1	1,112	99.7	2	1,175	97.2	15	1,137
450	99.9	1	1,091	99.6	2	1,111	99.5	1	1,173	96.0	13	1,122
433	99.7	5	1,090	99.3	6	1,109	98.8	17	1,172	94.1	32	1,109
417	98.9	12	1,085	98.7	6	1,103	97.2	20	1,155	91.4	30	1,077
400	97.5	18	1,073	97.7	18	1,097	94.4	45	1,135	87.9	51	1,047
383	95.4	29	1,055	95.0	42	1,079	90.2	55	1,090	83.6	48	996
367	91.9	47	1,026	90.3	62	1,037	84.8	72	1,035	78.0	84	948
350	86.4	72	979	84.0	78	975	77.7	96	963	70.1	98	864
333	79.6	78	907	76.0	100	897	68.5	121	867	60.8	119	766
317	71.0	108	829	66.7	108	797	58.6	112	746	50.7	116	647
300	60.3	127	721	56.6	118	689	57.4	151	634	40.4	124	531
283	49.2	114	594	45.3	132	571	36.0	117	483	30.8	98	407
267	39.0	108	480	35.4	90	439	27.1	94	366	22.2	103	309
250	29.1	108	372	26.7	103	349	18.7	104	272	15.0	64	206
233	20.5	81	264	18.0	92	246	11.5	65	168	10.0	51	142
217	13.7	67	183	10.7	70	154	6.7	49	103	6.0	42	91
200	8.5	46	116	5.6	43	84	3.7	22	54	2.9	30	49
183	5.3	25	70	3.1	14	41	2.1	15	32	1.2	11	19
167	3.3	17	45	1.9	12	27	1.2	5	17	0.6	2	8
150	2.0	13	28	1.3	2	15	0.8	5	12	0.5	1	6
133	1.1	7	15	1.0	4	13	0.6	1	7	0.4	0	
117	0.7	1	8	0.6	4	9	0.5	1	6	0.4	1	5
100	0.3	7	7	0.2	5	5	0.2	5	5	0.2	4	4
	Mean	=	282.8	Mean	=	289.5	Mean	=	304.1	Mean	=	319.3
	S.D	=	60.5	S.D	=	59.3	S.D	=	59.8	S.D	=	69.9
	Z score	=	− 0.41	Z score	=	− 0.32	Z score	=	− 0.11	Z score	=	+ 0.11

CMS	7th grade			8th grade			TOTAL		
	A	B	C	A	B	C	A	B	C
600	99.7	7	1,271	99.0	27	1,306	99.7	38	7,122
583	99.4	0		97.9	1	1,279	99.4	3	7,084
567	99.4	1	1,264	97.7	4	1,278	99.4	5	7,081
550	99.3	3	1,263	97.5	1	1,274	99.3	6	7,076
533	98.9	7	1,260	97.2	6	1,273	99.2	13	7,070
517	98.5	2	1,253	96.9	2	1,267	99.0	6	7,057
500	98.2	7	1,251	96.5	10	1,265	98.8	28	7,051
483	97.4	12	1,244	95.8	8	1,255	98.4	29	7,023
467	96.3	17	1,232	94.4	27	1,247	97.8	62	6,994
450	95.0	16	1,215	92.3	28	1,220	96.9	61	6,932
433	93.1	31	1,199	89.6	43	1,192	95.5	134	6,871
417	90.8	27	1,168	86.1	49	1,149	93.6	144	6,737
400	87.3	63	1,141	81.4	75	1,100	90.7	270	6,593
383	82.5	58	1,078	75.5	79	1,025	86.6	311	6,323
367	76.1	105	1,020	68.3	108	946	81.1	478	6,012
350	67.9	105	915	59.7	116	838	73.7	565	5,534
333	58.3	139	810	50.0	139	722	64.9	696	4,969
317	47.2	142	671	39.4	137	583	54.9	723	4,273
300	36.1	140	529	28.3	153	446	44.1	813	3,550
283	26.2	111	389	18.8	95	293	33.7	667	2,737
267	18.9	76	278	12.7	64	198	25.3	535	2,070
250	13.3	65	202	8.5	45	134	18.1	489	1,535
233	8.5	57	137	5.4	38	89	12.0	384	1,046
217	4.8	38	80	3.3	16	51	7.3	282	662
200	2.2	27	42	1.8	23	35	4.0	191	380
183	1	5	15	0.7	5	12	2.1	75	189
167	0.6	4	10	0.4	3	7	1.3	43	114
150	0.4	1	6	0.3	1	4	0.8	23	71
133	0.4	1	5	0.2	0		0.6	13	48
117	0.2	0		0.2	1	3	0.4	8	35
100	0.2	4	4	0.1	2	2	0.2	27	27
	Mean	=	325.3	Mean	=	342.3	Mean	=	311.8
	S.D	=	70.7	S.D	=	76.6	S.D	=	70.0
	Z score	=	+ 0.19	Z score	=	+ 0.44	Z score	=	0.0

A: Percentile ranks
B: Number of students
C: Accumulates number

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Table 6. Percentile Ranks of Achievement Scores of the Sample Students

Number of correct items	3rd grade			4th grade			5th grade			6th grade		
	A	B	C	A	B	C	A	B	C	A	B	C
20	99.9	0		99.9	1	1,113	99.6	9	1,178	99.2	18	1,159
19	99.9	1	1,090	99.6	6	1,112	97.7	36	1,169	97.0	33	1,141
18	99.6	7	1,089	98.9	11	1,106	93.3	67	1,133	93.1	57	1,108
17	98.6	15	1,082	96.9	33	1,095	86.8	86	1,066	86.1	106	1,051
16	96.4	33	1,067	92.3	70	1,062	78.8	104	980	75.2	147	945
15	92.6	49	1,034	85.4	83	992	68.1	147	876	63.6	122	798
14	87.2	68	985	75.6	136	909	55.9	140	729	51.9	149	676
13	79.9	92	917	63.4	135	773	44.5	130	589	39.9	128	527
12	70.0	125	825	50.4	153	638	33.8	121	459	29.7	109	399
11	58.4	126	700	38.7	109	485	24.4	100	338	21.4	83	290
10	47.8	107	574	27.9	131	376	17.5	64	238	14.6	76	207
9	37.1	125	467	18.2	84	245	12.5	54	174	9.2	48	131
8	25.2	134	342	11.8	60	161	8.0	51	120	5.7	33	83
7	15.4	80	208	7.1	45	101	4.7	28	69	3.4	22	50
6	9.6	46	128	3.8	28	56	2.7	19	41	1.7	17	28
5	5.3	49	82	1.9	13	28	1.4	12	22	0.8	3	11
4	2.0	22	33	0.9	10	15	0.8	2	10	0.5	5	8
3	0.8	5	11	0.3	3	5	0.4	6	8	0.2	2	3
2	0.4	4	6	0.1	1	2	0.1	1	2	0.1	1	1
1	0.1	2	2	0.1	1	1	0.0	1	1	0.1	0	
	Mean	=	10.2	Mean	=	11.8	Mean	=	13.2	Mean	=	13.6
	S.D	=	3.2	S.D	=	3.0	S.D	=	3.4	S.D	=	3.2
	Z score	=	−0.80	Z score	=	−0.39	Z score	=	−0.00	Z score	=	+0.10

Number of correct items	7th grade			8th grade			TOTAL		
	A	B	C	A	B	C	A	B	C
20	98.5	39	1,269	96.0	104	1,304	98.8	171	7,122
19	93.3	91	1,230	85.2	177	1,200	95.2	344	6,951
18	85.3	113	1,139	71.1	192	1,023	89.6	449	6,607
17	75.5	137	1,026	57.8	155	831	82.7	533	6,158
16	65.1	126	889	45.6	163	676	74.5	643	5,625
15	53.5	168	763	34.5	125	513	65.1	694	4,982
14	41.9	126	595	25.7	106	388	55.1	727	4,288
13	32.9	104	469	18.7	77	282	45.3	667	3,561
12	24.9	99	365	13.7	53	205	36.0	661	2,894
11	18.4	66	266	9.6	54	152	27.6	538	2,233
10	13.6	54	200	6.3	32	98	20.5	465	1,695
9	9.1	61	146	3.9	30	66	14.4	402	1,230
8	5.4	34	85	2.2	14	36	9.3	326	828
7	3.4	16	51	1.4	8	22	5.6	200	502
6	2.1	16	35	0.8	6	14	3.3	132	302
5	1.1	11	19	0.5	3	8	1.7	91	170
4	0.5	4	8	0.2	4	5	0.8	47	79
3	0.2	4	4	0.1	1	1	0.3	21	32
2	0.1	0		0.1	0		0.1	7	11
1	0.1	0		0.1	0		0.1	4	4
	Mean	=	14.3	Mean	=	15.8	Mean	=	13.2
	S.D	=	3.5	S.D	=	3.2	S.D	=	3.7
	Z score	=	+0.29	Z score	=	+0.69	Z score	=	+0.00

A: Percentile ranks
B: Number of students
C: Accumulates number

Stage 5

The distinctive features in this stage are as follows:

1. a concept that is very easy to connect with familiar experience, such as, the height of a hill connecting to the slope of the hill side (item 4);
2. the concept that often exists as different between different measuring scales, such as item 11.

From Table 2 we can see that, for each item, once the increasing numbers of percentage of students' grades begin to reach seventy or more at a certain grade, it would then increase in a stable form in the successive grades. It means that, from that grade, the development of that concept of students would keep growing successively. Therefore, we suggest that the appropriate time for teaching a particular concept should be one or two grades before that grade at which the percentage number of students reaches seventy or more the first time. The suggested grade for teaching each item is also listed in Table 4.

From Table 5, we can see that the average values of students' CMS keep increasing from the third grade up to the eighth grade. It indicates the growing of students' science conceptual development with their ages. Using the data on Table 5, we plotted the norm curves of CMS showing from Fig. 1.1 to Fig. 1.7. They were nearly of normal distribution. This means that, the samples we used to analyze the students' conceptual development of time and spaces were suitable for establishing the norm of CMS.

In Table 6, both the average values of conceptual achievement scores and the modes of the students from the third grade up to the eighth grade kept increasing. From this evidence we can say that the students' conceptual development of time and space were indeed increasing with their ages. Among the norm curves shown in Fig. 2.1 to Fig. 2.7 that were plotted with the data on Table 6, we can see that the higher the grades, the more their norm curves deviated from the normal distributions. Therefore, the rating scales of this study were more suitable for judging the conceptual development of the students in the lower grades.

From the average values of students' achievement scores in Table 7, we can see that, the conceptual achievements of students had something to do with the categories of each of their backgrounds. The rank orders of the categories in each of their backgrounds arranging from higher achievement scores to lower ones are shown in the following:

1. Rank orders of fathers' occupations are: (1) education, (2) government employees, (3) liberal professions, (4) businessman, (5) working men and (6) farmers or fishermen.
2. Rank orders of mothers' occupations are: (1) education, (2) government employees, (3) liberal professions, (4) housewife,. (5) business women, (6) working women, and (7) farmers or fishermen.
3. Rank orders of the education both of their fathers and mothers are: (1) university and graduate school, (2) junior college, (3) senior high school, (4) junior middle school, and (5) primary school.
4. Rank orders of living regions had no difference among all the cities and counties except some small villages located far from the big cities or near the boundaries of counties such as villages of fishermen and the villages in mountainous region. The achievement scores of the students in these regions were of lower magnitudes.
5. Rank orders of students' CMS are (1) level 6, (2) level 5, (3) level 4, (4) level 3, (5) level 2, and (6) level 1.

V. Conclusion and Suggestions

1. Conclusion

(1) The time and space conceptual developments of the students in our country were indeed increasing with their ages.

(2) All the 20 items in the rating scale were good for judging the time and space conceptual development of students.

(3) The time and space concepts in the rating scale could be classified into five stages as shown in Table 4.

(4) The suggested grade for teaching these concepts in school are shown in Table 4.

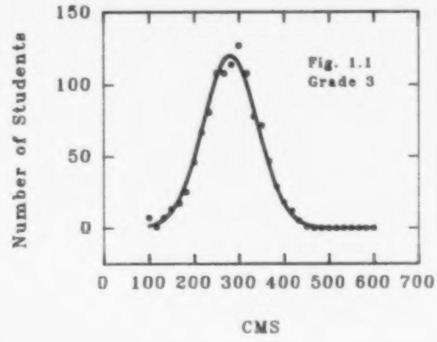
(5) The samples used to study the conceptual development of time and space in this study corresponded to the samples of the norm of CMS development.

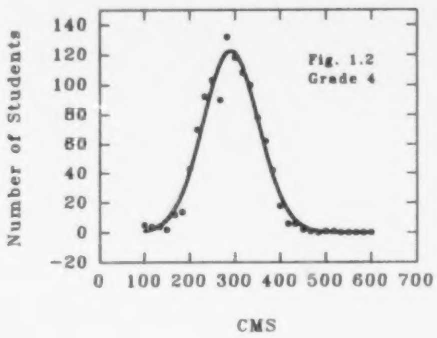
(6) The rating scale made by this study was more suitable for judging the time and space conceptual development levels of the students in the lower grades.

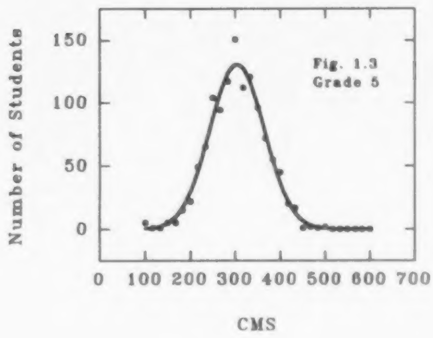
(7) The factor of students' backgrounds influenced the achievements of students' time concepts more than their space concepts.

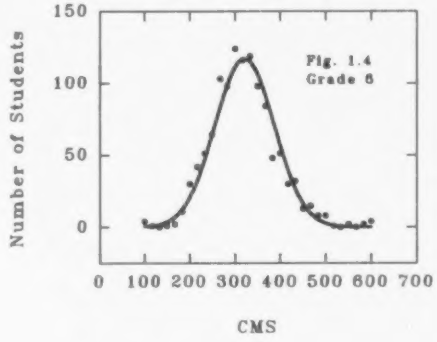
(8) Time concepts of the students in all of the grades are related to their fathers' occupations, their mothers' education, and their own CMS.

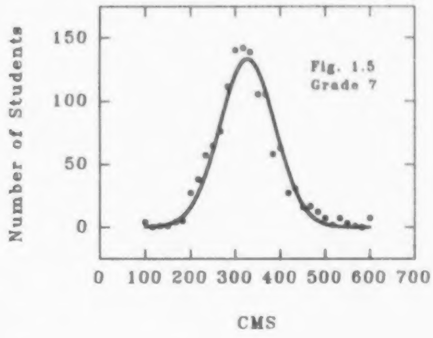
(9) Time and space concepts of the students in all

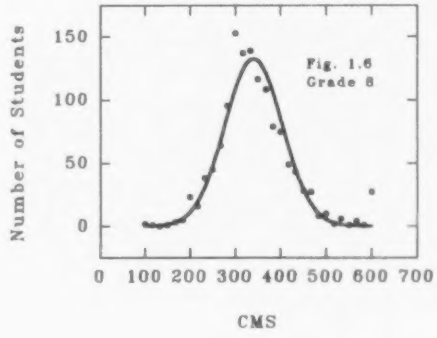












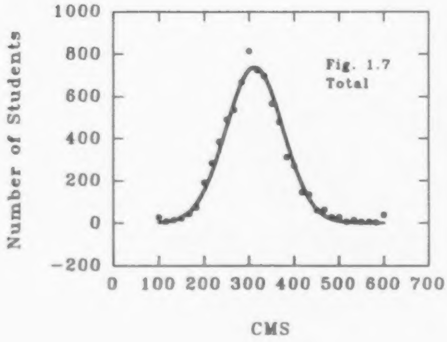
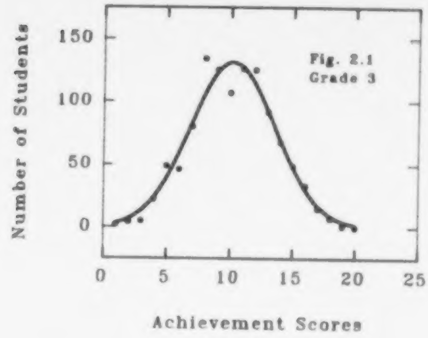
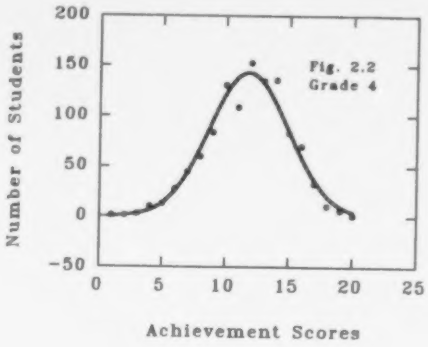
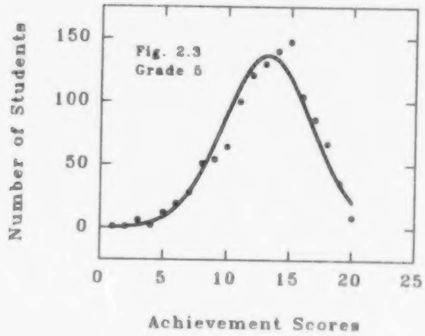
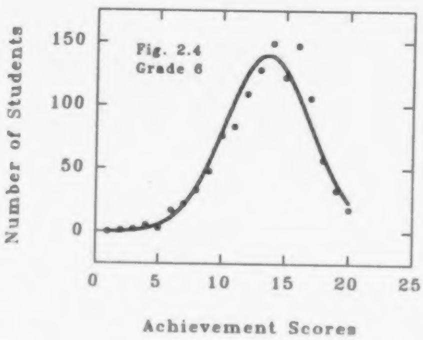


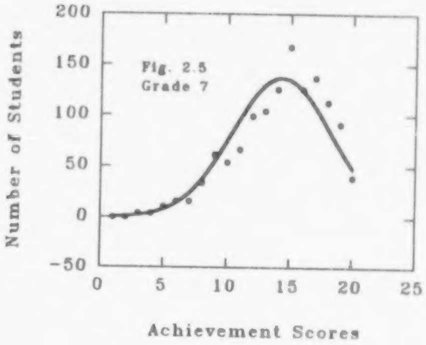
Fig. 1. Graphs of the number of students from grade 3 to grade 8 as well as the total number of students with respect to their CMS

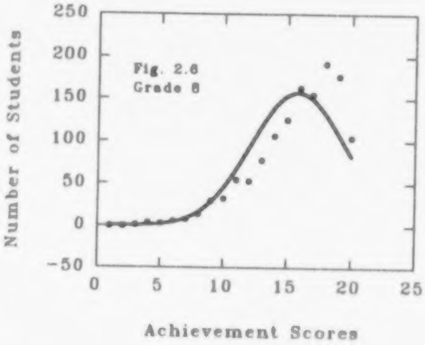












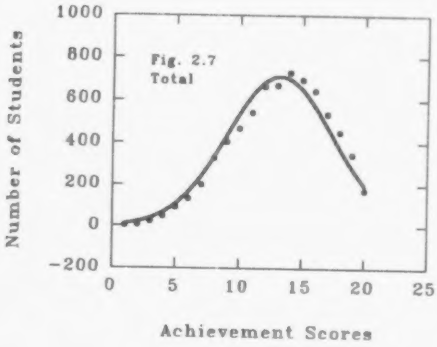


Fig. 2. Graphs of the number of students from grade 3 to grade 8 as well as the total number of students with respect to their achievement scores

of the grades are related to the student's CMS.

(10) Rank orders of fathers' occupations arranged in accordance with the conceptual achievement scores are: (a) education, (b) government employees, (c) liberal professions, (d) businessman, (e) working men, and (f) farmers or fishermen.

(11) Rank orders of mothers' occupations arranged in accordance with the conceptual achievement scores are: (a) education, (b) government employees, (c) liberal professions, (d) housewife, (c) business women, (f) working women, and (g) farmers or fisher women.

(12) Rank orders of education both of fathers and mothers arranged in accordance with the students' achievement scores are: (a) university and graduate school, (b) junior college, (c) senior high school, (d) junior high school, and (e) primary school.

(13) Rank orders of living regions had no difference among all the cities and counties except some small villages located far from the big cities or near the boundaries of counties such as villages of fishermen and the villages in mountainous regions. The achievement scores of the students in these regions were of lower magnitudes.

(14) Rank orders of students' CMS arranged in accordance with the students' achievement scores are: (a) level 6, (b) level 5, (c) level 4, (d) level 3, (e) level 2, and (f) level 1.

2. *Suggestions*

(1) Data in Table 4 can be provided as a reference to the related organizations and teachers for editing textbooks.

(2) Data in Table 7, the relationships among the students' conceptual developments and the categories of each background of students, provided as a reference to schools and teachers for counseling students' school work.

(3) We couldn't see any difference of students' con-

Table 7. Average Scores of the Sampling Students in Each Grade Classified by the Categories of Their Father's Occupation

Categories of father's occupation	Government employees	Education	Liberal professions	Businessman	Workman	Farmers and fishermen	
Average score	14.1	14.9	13.5	13.5	13.0	12.5	
Categories of mother's occupation	**Government employees**	**Education**	**Liberal professions**	**Businessman**	**Workman**	**Farmers and fishermen**	**Housewife**
Average scores	14.0	15.3	13.8	13.3	13.0	12.7	13.4
Categories of father's education	**Graduate school**	**University**	**Junior college**	**Senior high school**	**Junior high school**	**Primary school**	
Average scores	15.1	14.7	14.6	13.7	13.1	13.0	
Categories of mother's education	**Graduate school**	**University**	**Junior college**	**Senior high school**	**Junior high school**	**Primary school**	
Average scores	16.8	14.9	14.9	14.0	13.3	13.0	
Categories of living regions	**Cities**	**Counties**	**Towns**	**Small towns**	**Small villages**		
Average scores	13.2	13.2	13.2	13.2	12.9		
Categories of CMS	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**	
Average scores	10.2	11.9	13.1	13.7	14.7	17.0	

ceptual developments among the current living regions we divided them into. We suggest that we should analyze it again after re-dividing the living regions.

(4) Most of the students in the lower grades did not know how to write the references of their backgrounds. This fact probably had a negative influence on data analyzing. We suggest that the schools should provide the detailed references of each student's background.

(5) The data collected by this study should be analyzed further to get more information about the students' conceptual development of time and space.

Acknowledgments

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References

Ausubel, D.P. (1986). *Educational psychology: A cognitive view*. New York: Holt, Reinhart and Winston.

Bar, V. (1989). Introducing mechanics at the elementary school. *Physics Education, 24*(6), 384-352.

Bruner, J.B., Goodnow, J.J., & Austin G.A. (1977). *A study of thinking*. New York: John Wiley.

Bruner, J.S. (1966). *Toward a theory of instruction*. Cambridge: Harvard University Press.

Clement, J. (1982). Student's preconceptions in introductory mechanics. *American Journal of Physics. 50*(1), 66-71.

Gou, C.J. (1988). On learning science: A review of research from cognitive perspectives. *Journal of National Taiwan College of Education, 13*, 351-379. (In Chinese)

Hung, M.L. (1991). *Child's cognition approach to the conceptual mechanism in Newton's law* (Research report of NSC). Taipei: National Science Council. (In Chinese)

Linn, M.C. (1987). Establishing a research base for science education: Challenges, trends, and recommendations. *Journal of Research in Science Teaching, 24*(3), 191-216.

Piaget, J. (1952). *The origins of intelligence in children*. New York: International Universities Press.

Piaget, J. (1963). *The psychology of intelligence*. Paterson, N.J.: Littlefield, Adams.

Piaget, J. (1977). *The construction of reality in the child*. New York: Ballantine Books.

Piaget, J. (1970). *The child's conception of movement and speed*. London: Routledge and Kegan Paul.

Piaget, J. (1969). *The psychology of the child*. Translated by Helen Weaver. New York: Baxic Books.

Appendix
Rating Scale for Conceptual Development of Space and Time of Children

School ____________ Grade ____________ Name ____________ Sex ____________ Age ____________

Father's occupation ______________________________ Father's education ______________________________

Mother's occupation ______________________________ Mother's education ______________________________

( ) 1. There are two plastic tubes A and B as shown in Fig. 1, which one is longer?
(1) A is longer.
(2) B is longer.
(3) A and B are of the same length.
(4) I don't know how to distinguish them.

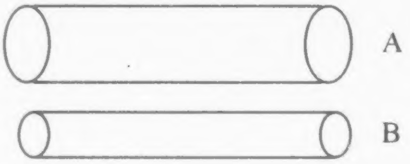

Fig. 1.

( ) 2. John is walking along a straight road from A to B, while Peter is walking along a curved road from C to D as shown in Fig. 2.
(1) Straight road is longer.
(2) Curved road is longer.
(3) They are of the same length.
(4) I don't know how to distinguish them.

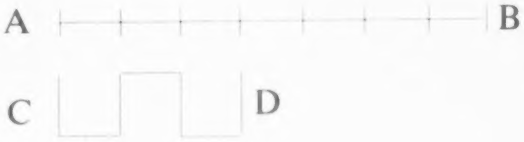

Fig. 2.

( ) 3. Fig. 3 represents a small hill. John walked up along the hill side from place A to the place B at the top of the hill, then he walked down from the top to place A along the original path. Which one of these two paths is longer, up hill or down hill?
(1) The path up the hill is longer.
(2) The path down the hill is longer.
(3) These two paths are of the same length.
(4) I don't known how to distinguish them.

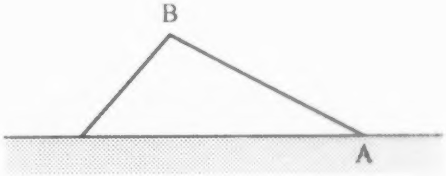

Fig. 3.

( ) 4. Fig. 4 represents a small hill. John climbed up along the right side of the hill from place A to the top B of the hill, while Peter climbed up along the left side of the hill from place C to the top B. Which of them climbed higher?
(1) John climbed higher.
(2) Peter climbed higher.
(3) They climbed the same height.
(4) I don't know how to distinguish their heights.

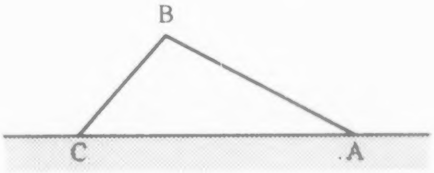

Fig. 4.

(   ) 5. Which one of the areas in Fig. 5 is larger?
(1) Area A is larger.
(2) Area B is larger.
(3) Area A and B are the same.
(4) I don't know how to distinguish their areas.

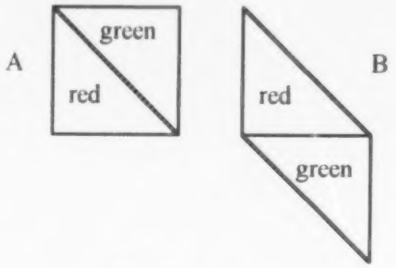

Fig. 5.

(   ) 6. Which volume of these two piles of wooden blocks as shown in Fig. 6 is larger?
(1) A is larger.
(2) B is larger.
(3) They are of the same volume.
(4) I don't know how to distinguish their volumes.

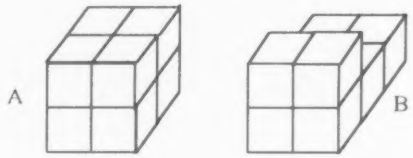

Fig. 6.

(   ) 7. We pour into two containers A and B, as shown in Fig. 7, the water filling in the measuring glass. Which one of the following statements is correct?
(1) A has more water.
(2) B has more water.
(3) They have the same amount of water.
(4) I don't know how to tell them apart.

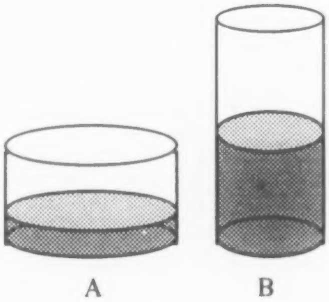

Fig. 7.

(   ) 8. John filled the paper box with ping-pong balls as shown in Fig. 8. How many balls are there do you think?
(1) There are 8 balls.
(2) There are 12 balls.
(3) There are 16 balls.
(4) There are 20 balls.

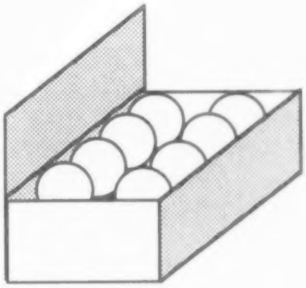

Fig. 8.

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9. John stands at the center of the circle facing the train station. Train station is on the north side of John as shown in Fig. 9.

( ) 9.1. What place is on the left side of John?
(1) Park. (2) Hospital.
(3) School. (4) Train station.

( ) 9.2 What place is on the east side of John?
(1) Park. (2) Hospital.
(3) School. (4) Train station.

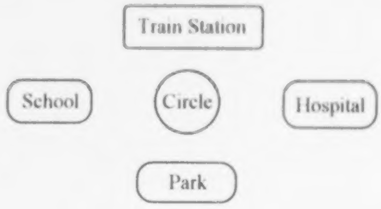
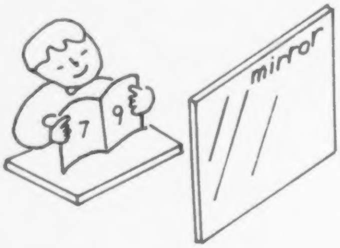
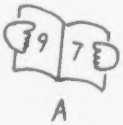
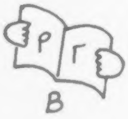


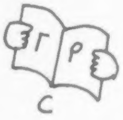
Fig. 9.

( ) 10. John is sitting before the mirror reading a book. When he looks at the image in the mirror, what will the two numbers "7" and "9" on the cover of the book look like?
(1) It looks like picture A.
(2) It looks like picture B.
(3) It looks like picture C.
(4) I do not know.





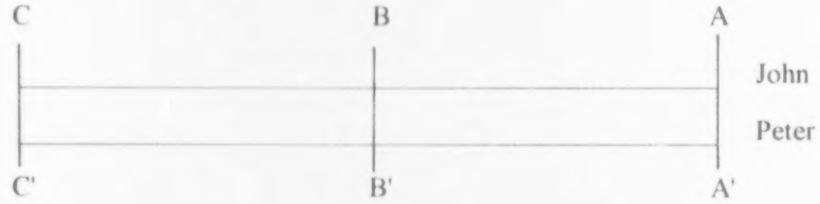




( ) 11. John and Peter together took part in a two hundred meter race on foot. Their brothers were estimating time with different methods outside the field. When John had finished his running, his brother was counting 40 by clapping hands in applause. When Peter had finished his running, his brother was also counting 40 by measuring his heart beats. Whose running time was longer?
(1) John's running time was longer. (2) Peter's running time was longer.
(3) Their running time was the same. (4) They couldn't be compared.

( ) 12. John finished his homework before Peter, while Mary finished her homework before John. Then between Mary and Peter, who finished first?
(1) Mary finished before Peter. (2) Peter finished before Mary.
(3) They finished at the same time. (4) I don't know.

( ) 13. John and Peter were running from the starting line A-A′ at the same moment with the same speed. John stopped at line B-B′, while Peter kept running and then stopped at line C-C′.



( ) 13.1. Who arrived at his own end line first?
(1) John. (2) Peter.
(3) They arrived at the same time. (4) I don't know.

( ) 13.2. The time when John arrived at line B-B′ was twelve o'clock at noon. What was the time when Peter arrived at line C-C′.
(1) Before twelve o'clock. (2) At twelve o'clock too.
(3) After twelve o'clock. (4) I don't know.

( ) 13.3. Were they running in the same period of time?
(1) The time of John was longer. (2) The time of Peter was longer.
(3) They were running in the same period of time. (4) I don't know.

( ) 13.4. During the time when John arrived at line B-B′, Peter was just reaching line C-C′. Were they running in the same period of time?
(1) The time of John was longer. (2) The time of Peter was longer.
(3) They were running in the same period of time. (4) I don't know.

14. There are four seasons in one year. They are circulating in the order of spring, summer, autumn, and winter. In our country, the first season of the year is spring. The orders of the successive seasons are summer, autumn, and winter.

( ) 14.1. Suppose there is a country. Its first season of the year is summer. What is the order of the successive year?
(1) They are autumn, winter, spring.
(2) They are spring, autumn, winter.
(3) They are winter, autumn, spring.
(4) They are spring, winter, autumn.

( ) 14.2. What season follows winter?
(1) Autumn. (2) Summer. (3) Spring. (4) I don't know.

( ) 14.3. What season comes before winter?
(1) Autumn. (2) Summer. (3) Spring. (4) I don't know.

兒童時間與空間概念之發展

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摘　要

本研究之目的在瞭解我國學生對時間與空間概念發展之現況，樣本以台灣南部八縣市各地區小學三年級至國中二年級（八年級）之全體學生爲範圍，用隨機取樣中集體取樣法獲得樣本7122人。

資料之蒐集沿用洪木利教授發展之「實象預測法」(Demonstration－lead－to－prediction Test)爲之。

量測工具爲本研究自行發展，經專家效度、建構校度及重測信度確定其概念範圍之適當性及樣本群體之穩定性。

研究結果發現，我國學生時間與空間概念可分爲五個發展階段。而此概念的發展有隨年級增加之趨勢，科學概念成熟分數(CMS)亦隨年級俱增，CMS百分等級常模成常態分佈。各年級學生時空概念發展之狀況與學生之背景（父教、父職、母教、母職、地區及CMS）有顯著關係。本研究依此發展特性，提出建議性之授課時間表。

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Realization of Robot Motion Based on a Teaching Pad

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ABSTRACT

In this paper, a laboratory setup for teaching and research in the construction of a teaching pad for a "playback" robot is proposed. This system applies microcomputer software and hardware to develop a special teaching pad, which can match the necessity of industrial production.

This teaching pad provides simple operations and quick responses, which are important elements in the development of robots and match the principle for labor-saving in industrial production. Results of some test cases are presented in this paper.

Key words: teaching pad, playback robot, microcomputer

I. Introduction

When the robot replaces human operators in an application that is physically uncomfortable and potentially dangerous to their health, the results are of double value. However, precision, speed and repeatability are common threads running through the heart of every successful robot application. Without them, human decisions and their attentive considerations must be added back into the equipment operations and many advantages of robots will be lost. Although it is true that the simple playback pneumatic robot is discussed in this paper, the best manufactured pneumatic robot cannot perform its planned criteria if its teaching pad is not properly designed.

These papers study the design concepts for pneumatic robots (Mack, 1990a; Mack, 1990b; Fleischer, 1990; Schneider, 1990). All of their techniques are based on the determination of the processes that can be automated. The designers must choose between dedicated devices that can only perform one function and robotic devices that are reprogrammable to accommodate changes in products or other conditions. Curless proposed a method; applying computer control to add speed and accuracy for a programmable automatic tool changer (Curless, 1986). In order to ensure position accuracy and speed requirements, logic elements are adopted to form the control circuit of a manipulator (Rubinger, 1988). The master/slave manipulator, which is operated remotely from a safe location, performs maintenance work in areas contaminated by radiation. The designers have included touch-sensitive feedback from the slave arm so that the force experienced by the slave arm is transmitted back to the master (Stricklin, 1988). Many methods described for generating a trajectory make it possible to obtain an attractively low memory requirement for the description of many tasks in a teaching mode (Couderc, 1987; Schreiber, 1984; Kawamura *et al.*, 1988).

Besides, this circuit adopts photocouples to eliminate relay disadvantages, because relay logic systems sufer from some inherent problems (Fadul *et al.*, 1992; Mendez *et al.*, 1986; Bachiochi, 1990). These problems can be summarized as follows:

(1) As the control system grows in complexity, the number of relays grows almost exponentially.
(2) An aging control system breaks down more often, causing production problems.

(3) Relay logic systems can be difficult and complex to troubleshoot since several operations can be incorporated to do one simple operation.

(4) Relays are analog devices made up of coils and contacts. Coils are opened or closed accordingly to provide the proper voltage at the proper time where necessary. These relays often suffer from mechanical fatigue as they age due to constant opening and closing. This will cause problems in reliability of the machine.

(5) Relays and their associated analog timers are expensive. Control relays typically cost slightly less then $100, while control timers can cost hundreds of dollers.

(6) Timing in relay logic is done through the use of analog timers. Analog timers are electromechanical devices that use an RC network to open or close a switch, based upon the time constant of the RC network. The time constant of the RC network can be adjusted manually via a knob on the outside of the timers case. These timers are notorious among maintenance personnel for causing problems. Timers also suffer from mechanical fatigue, as well as operator error. For example, if an operator "adjusts" one of the timers, the entire system can be made defunct.

(7) The relays are relatively slow. Their switchings are in milliseconds rather than microseconds (Money, 1985). They also suffer from contact bounce which can generate electrical noise (Lawrence and Mauch, 1987). This noise, if inductively or capacitively coupled to the controller circuit, can affect their operation.

The full functional capabilities of the employed teaching pad are utilized. Besides, the photocouple was adopted into the proposed circuit, which can overcome relay disadvantages such as troubleshooting, high cost, switching time, noise immunity, etc.

II. Description of Laboratory Setup

In this paper, a pneumatic robot for pick-and-place operation is proposed. The actuator of the robot is a combination of 4 pneumatic cylinders. Figure 1 shows its outward appearance. This robot is used to remove the finished product from the process machine. Table 1 shows the specification of the manufactured robot. Figure 2 shows the trajectories for pick-and-place operations. These trajectories can be changed easily, by means of operating the teaching pad. Figure 3 shows the pneumatic circuit for the actuators. Every cylinder is controlled by a 2-position magnetic valve.

Table 1. Specification of the Manufactured Robot

Power	AC 220V, 50/60 Hz
Maximum power	Max 220V, 2A
Air pressure	3 kg/cm^2
Maximum air pressure	7 kg/cm^2
Actuators	Pneumatic
"Maximum route"	
up-down	60 cm (adjustable)
forward-backward	6 cm (adjustable)
rotate	90° (adjustable)
"picking load"	
under 3 kg/cm^2	0.5 kg
Weight	30 Kg

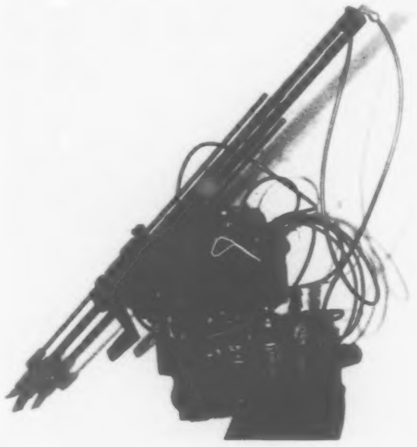


Fig. 1. Simple pneumatic playback robot

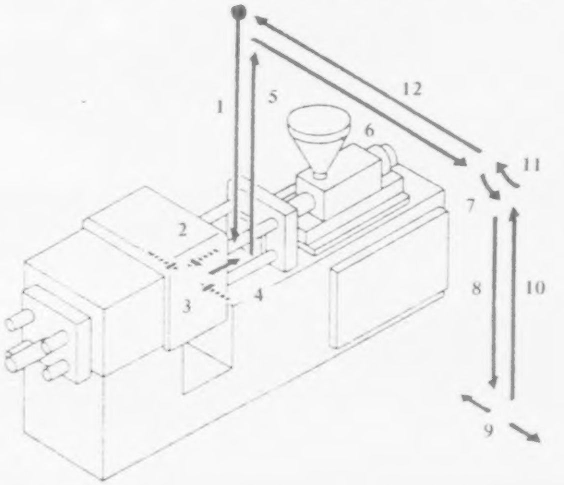


Fig. 2. Pick-and-place procedures for a process machine

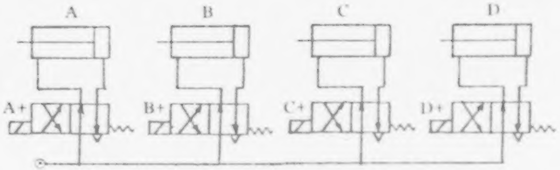


Fig. 3. Pneumatic circuit for playback robot

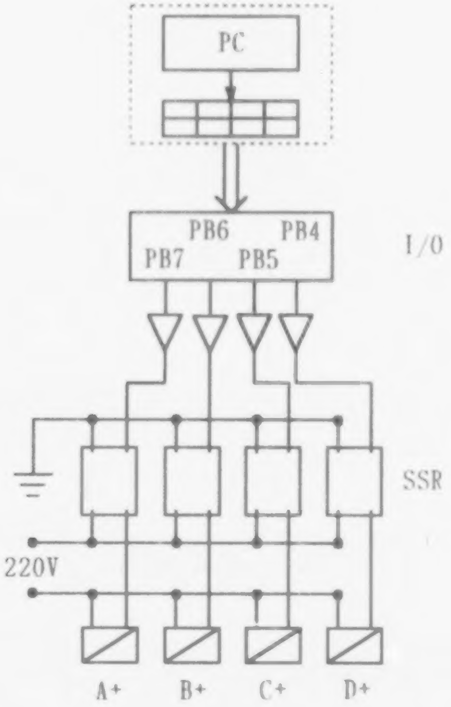

PC
PB6
PB4
PB7
PB5
I/O
SSR
220V
A+
B+
C+
D+

Fig. 4. Microcomputer-based I/O control circuit

Table 2. Bit-function Assignment for Port B

State	1	0
Port B		
PB7	down	up
PB6	forward	backward
PB5	rotate cw	rotate ccw
PB4	pick	place

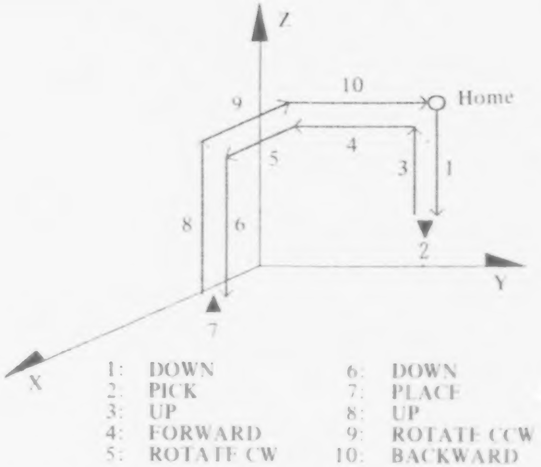

Z
Home
Y
X
10
9
4
5
3
1
2
8
6
7
1: DOWN
2: PICK
3: UP
4: FORWARD
5: ROTATE CW
6: DOWN
7: PLACE
8: UP
9: ROTATE CCW
10: BACKWARD

Fig. 5. Trajectories for pick-and-place operations

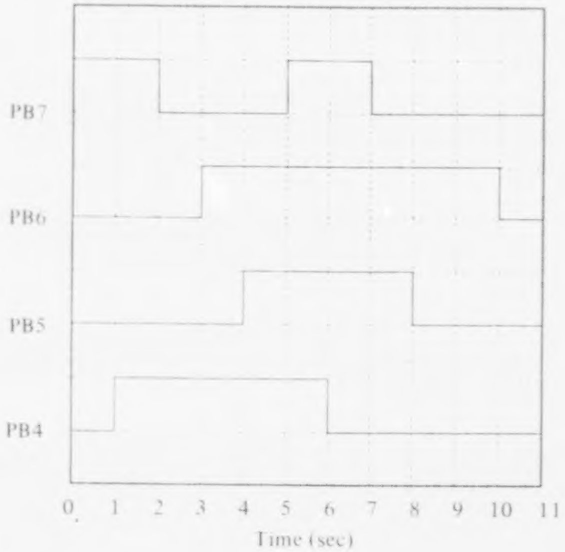


Fig. 6. Trajectories for pick-and-place operations

The magnetic valve adopted here requires AC 220 V as the power source. Figure 4 shows the micro-computer-based control circuit, which is interfaced with the external hardware via an input/output (I/O) card. The computer in this setup is a PC/AT type. However, a basic PC computer would also be adequate for the job. Table 2 assigns a bits' function for port B. In this experiment 4 bits of port B are used to control 4 magnetic values of these pneumatic cylinders.

III. Operation of Setup

After the pick-and-place robot is installed in an automatic machine, the motion trajectories of the robot should be mapped out (cf. Figure 5). Figure 6 shows the time sequence for its motion trajectories. The test program 1 is listed in appendix 1.

On the other hand, if the robot is installed in another automatic machine, the motion trajectories may be different (cf. Figure 7). Figure 8 shows the time sequence for its new motion trajectories. The test program 2 is listed in appendix 2.

From the above two examples, we can find that if the motion trajectories are changed, then the program data should be changed correspondingly. However, it is inconvenient to revise the software by a worker who is totally unfamiliar with the software. Moreover, every kind of automatic machine has different productive pro-

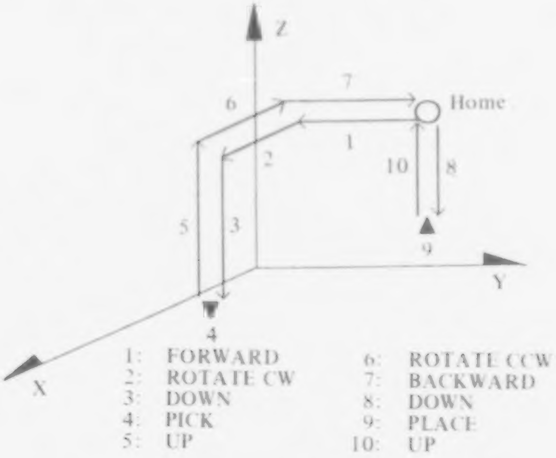

Z
Y
X
Home
1
2
3
4
5
6
7
8
9
10
1: FORWARD
2: ROTATE CW
3: DOWN
4: PICK
5: UP
6: ROTATE CCW
7: BACKWARD
8: DOWN
9: PLACE
10: UP

Fig. 7. Trajectories for pick-and-place operations

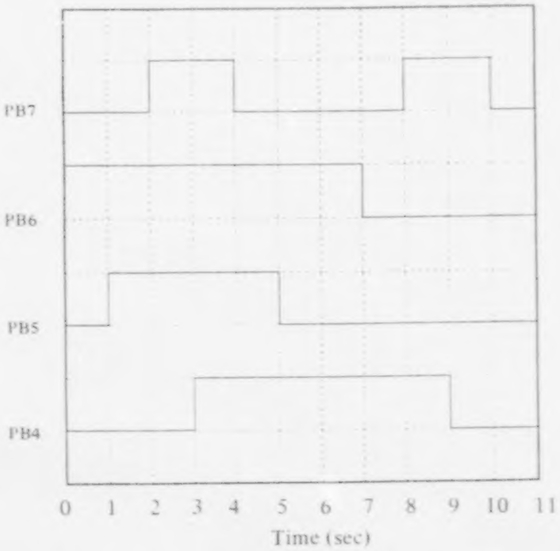


Fig. 8. Trajectories for pick-and-place operations

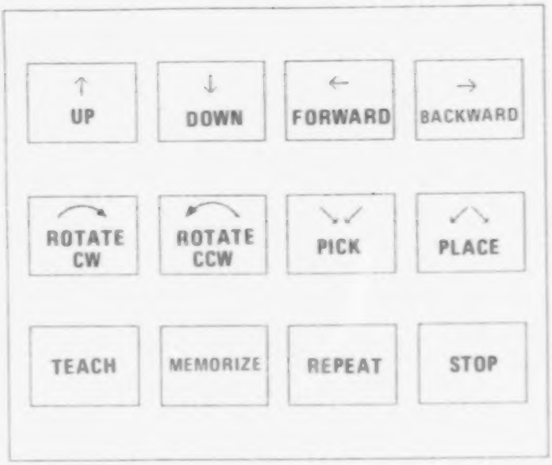

UP
DOWN
FORWARD
BACKWARD
ROTATE CW
ROTATE CCW
PICK
PLACE
TEACH
MEMORIZE
REPEAT
STOP

Fig. 9. Function keys for the teaching pad

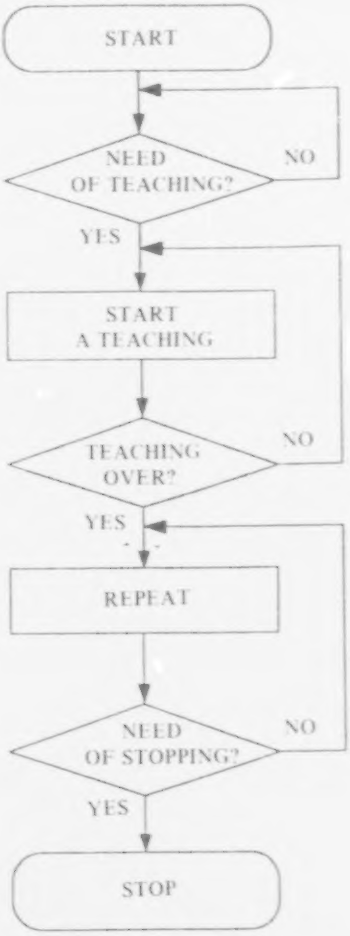
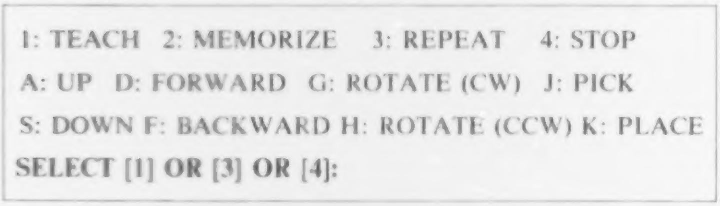
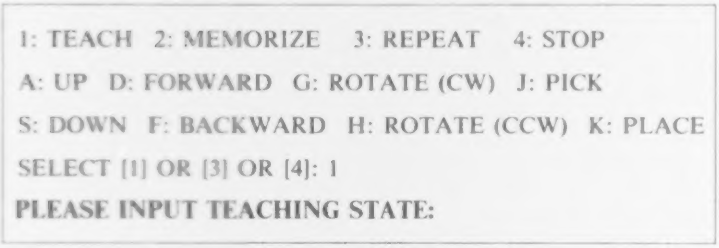

START
NEED OF TEACHING?
NO
YES
START A TEACHING
TEACHING OVER?
NO
YES
REPEAT
NEED OF STOPPING?
NO
YES
STOP

Fig. 10. Flow chart for the teaching pad software



```
1: TEACH  2: MEMORIZE   3: REPEAT   4: STOP
A: UP  D: FORWARD  G: ROTATE (CW)  J: PICK
S: DOWN F: BACKWARD H: ROTATE (CCW) K: PLACE
SELECT [1] OR [3] OR [4]:
```

Fig. 11. Instruction of test program



```
1: TEACH  2: MEMORIZE   3: REPEAT   4: STOP
A: UP  D: FORWARD  G: ROTATE (CW)  J: PICK
S: DOWN  F: BACKWARD  H: ROTATE (CCW)  K: PLACE
SELECT [1] OR [3] OR [4]: 1
PLEASE INPUT TEACHING STATE:
```

Fig. 12. Instruction of "TEACH" mode

cesses. No sooner have the productive structures been changed than the operator has to give industrial robots simple teachings in order to meet new tasks.

The teaching pad, with simple operations and quick responses, provides important elements in the development of robots and matches the principle for labor-saving in industrial production. In this setup, 12 function keys are chosen out of the computer key board, accompanied with a software program to form a teaching pad (cf. Figure 9). Figure 10 illustrates the principal features of the software program.

After test program 3 is run, some information will appear on the computer monitor (cf. Figure 11). The test program 3 is listed in appendix 3. If we select "1", in other words "TEACH" mode, then Figure 12 will appear on the computer screen. After that, the motion trajectories of the playback robot can be mapped out step by step.

IV. Conclusions

This paper has presented both hardware and software for the teaching pad. The proposed pneumatic components and microcomputer setup are built effectively and inexpensively. They can be used for the purpose of laboratory training and research. Relying on the teaching pad, every complex trajectory can be set up in minutes. Even for an unskilled worker, the entire teaching procedure is very simple. It is ideal for teaching the basics of generating and recording of industrial robots continuous trajectories.

Acknowledgement

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References

Bachiochi, J. (1990). Power control basics: Choosing the best digital power control option for your application. *Journal of Computer Application, 15,* 57-67.

Couderc, R., Fannecher, G., Poiraudeau, J.F., & Roux, S. (1987). A Method for the generation and recording of industrial robots continuous trajectories. *Robotica, 5,* 37-44.

Curless, R.A. (1986). Computer control adds speed and accuracy to hydraulic tool changer. *Hydraulics & Pneumatics, 8,* 77-80.

Fadul, F., Batistig, D., & Baum, M. (1992). Implementation of a microprocessor-based industrial machine. *Computers in Industry, 18,* 315-321.

Fleischer, H. (1990). Automate with air; Air filtration is essential to effective robot performance. *Hydraulics & Pneumatics, 8,* 44-45.

Kawamura, S., Miyazaki, F., & Arimoto, S. (1988). Realization of robot motion based on a learning method. IEEE Trans. *System, Man, Cybernetics, 18*(1), 126-134.

Lawrence, P., & Mauch, K. (1987). *Real-time microcomputer system design.* New York: McGraw-Hill.

Mack, J.F. (1990a). Automate with air; part 1: Basic design concepts for simple pneumatic robots. *Hydraulics & Pneumatics, 2,* 33-34.

Mack, J.F. (1990b). Automate with air; part 2: Modular standard components provide robotic design flexibility. *Hydraulics & Pneumatics, 3,* 39-41.

Mendez, A., Calleja, R., & Diez, V. (1986). Control improvement by low cost equipment. *Proc. IFAC,* 133-135.

Money, S. (1985). *Microprocessor in instrumentation and control.* New York: McGraw-Hill.

Rubinger, B. (1988). Manipulator has redundant-yet compact-hydraulics. *Hydraulics & Pneumatics, 7,* 77-82.

Schneider, R.T. (1990). Automate with air; Three examples of simple, pneumatic pick-and-place robots. *Hydraulics & Pneumatics, 11,* 33-35.

Schreiber, R.R. (1984). How to teach a robot. *Robotics Today,* 51-56.

Stricklin, C. (1988). Master/slave manipulator performs diverse task. *Hydraulics & Pneumatics, 9,* 123-124.

Appendix 1. The test program 1

```
100  REM TEST RPOGRAM 1.
110  DIM A(11)
120  REM PORT ADDRESS ASSIGNMENT.
130  PROTB=&H3E9: CTRLP=&H3EB
140  REM 8255A INITIALIZATION.
150  OUT CTRLP, &H99: REM CONTROL WORD
     #13.
160  OUT PB, 0
170  REM READ MOTION DATA.
180  FOR I=1 TO 11: READ A(I) : NEXT I
190  LOCATE 16,33: PRINT "HIT SPACE-BAR TO
    STOP"
200  REM OUTPUT MOTION DATA.
210  FOR I = 1 TO 11
220  OUT PB, A(I)
230  T = TIMER
240  IF (TIMER-T) < 1 THEN 240
250  A$ = INKEY$
260  IF A$ = "   " THEN END
270  NEXT I
280  GOTO 210
290  DATA 128,144,16,80,112,240,224,96,64,64,0
```

Appendix 2. The test program 2.

```
100  REM TEST PROGRAM 2.
110  DIM A(11)
120  REM PORT ADDRESS ASSIGNMENT.
130  PROTB = &H3E9: CTRLP = &H3EB
140  REM 8255A INITIALIZATION.
150  OUT CTRLP, &H99: REM CONTROL WORD
     #13.
160  OUT PB, 0
170  REM READ MOTION DATA.
180  FOR I = 1 TO 11: READ A(I): NEXT I
190  LOCATE 16, 33: PRINT "HIT SPACE-BAR TO
       STOP"
200  REM OUTPUT MOTION DATA.
210  FOR I = 1 TO 11
220  OUT PB, A(I)
230  T = TIMER
240  IF (TIMER-R) < 1 THEN 240
250  A$ = INKEY$
260  IF A$ = "   " THEN END
270  NEXT I
280  GOTO 210
290  DATA 64,96,224,240,112,80,80,16,144,128,0
```

Appendix 3. A software program for the teaching pad

```
100  REM TEST PROGRAM 3.
110  DIM A[50] : B[1,1,1,1,] : C[50] : D[50]
120  REM PORT ADDRESS ASSIGNMENT.
130  PORTB = &H3E9 : CTRLP = &H3EB
140  REM 8255A INITIALIZATION.
150  OUT CTRLP, &H99: REM CONTROL WORD
  #13.
160  OUT PB, 0
170  CLS
180  PRINT "1: TEACH 2: MEMORIZE 3: REPEAT
     4: STOP": PRINT
190  PRINT "A: UP D: FORWARD G: ROTATE
     (CW) J: PICK"
200  PRINT "S: DOWN F:BACKWARD H:
     ROTATE (CCW) K: PLACE":PRINT
210  N=0
220  OPEN "I", #1, "B: DATA"
230  IF EOF(1) THEN CLOSE: GOTO 290
240  INPUT #1, CODE%
250  A[N]%CODE⊙
260  PRINT A[N]; "      ";
270  N = N + 1
280  GOTO 230
290  LOCATE 13, 1: INPUT "SELECT [1] OR ]3] OR
        [4]:", A$
300  IF A$ = "1" THEN GOTO 420
310  IF A$ = "3" THEN GOTO 330
320  IF A$ = "4" THEN END ELSE BEEP; GOTO
     290
330  FOR I = 0 TO N—1
340  OUT PB, A[I]
350  LOCATE 14, 2: PRINT A[I]; "   "
```

```
360 T = TIMER
370 IF (TIMER-T) < 1 THEN 370
380 A$ = INKEY$
390 IF A$ = “4” THEN END
400 NEXT I
410 GOTO 330
420 PRINT
430 X=0: I=0: J=0: K=0: L=0
440 LOCATE 15: INPUT” PLEASE INPUT
    TEACHING STATE: “; A$
450 IF (A$ = “S”) OR (A$ = “s”) THEN I=1:
    GOTO 560
460 IF (A$ = “A”) OR (A$ = “a”) THEN I=0:
    GOTO 560
470 IF (A$ = “D”) OR (A$ = “d”) THEN J=1:
    GOTO 560
480 IF (A$ = “F”) OR (A$ = “f”) THEN J=0:
    GOTO 560
490 IF (A$ = “G”) OR (A$ = “g”) THEN K=1:
    GOTO 560
500 IF (A$ = “H”) OR (A$ = “h”) THEN K=1:
    GOTO 560
510 IF (A$ = “J”) OR (A$ = “j”) THEN L=1:
    GOTO 560
520 IF (A$ = “K”) OR (A$ = “k”) THEN L=1:
    GOTO 560
530 IF (A$ = “2”) THEN 620: GOTO 560
540 IF (A$ = “3”) THEN 700: GOTO 560
550 IF (A$ = “4”) THEN END ELSE BEEP: GOTO
    600
560 C[X] = I*128+J*64+K*32+L*16
570 PRINT C[X]
580 OUT PB, C[X]
590 X=X+1
600 LOCATE 15: INPUT “PLEASE INPUT NEXT
    STATE: “; A$
610 GOTO 450
620 OPEN “O”, #1, “B:DATA”
630 FOR I=0 TO X-1
640 D[O]
650 WRITE #1, D[I]
660 NEXT I
670 CLOSE #1: PRINT
680 PRINT “MEMERIZE ‘O.K.’ ”
690 GOTO 170
700 FOR I=0 TO X-1
710 OUT PB, D[I]
720 T = TIMER
730 IF (TIMER-T) < 1 THEN 730
740 PRINT D[I]
750 NEXT I
760 A$=INKEY$
770 IF A$=“4” THEN END
780 GOTO 700
```

利用教導器規劃機械手運動路徑

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摘　要

本文設計一套機械手教導器，可作爲教學以及研究使用，此教導器以微電腦軟體及硬體爲基本架構，它的功能符合產業界使用上的需求。

此教導器操作方法相當簡單，時間響應也很迅速，可節省人力，符合產業經濟的需求。本文記載詳細的實測結果。

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The Relationship between Contributions of Cooperative Vocational Education to Students and Components of Employers' Implementation

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ABSTRACT

The purpose of this study was to identify contributions of cooperative vocational education to students and their relationships with components of employers' implementation. The subjects used in the study were 324 teachers, 570 students and 684 graduates randomly selected from the individuals involved in the program; the data for the study were collected through the mailed questionnaire and analyzed by using the SPSSx package.

Teachers, students, and graduates positively agreed that cooperative vocational education was a contributory program to vocational high school students. However, there were several defects. Employers' implementation influenced contributions of the program through training, equipment, work environment, and compensation and fringe benefits. These components could explain 55 percent of the variance of contributions of the program.

Key words: cooperative education, vocational education, cooperative vocational education

I. Introduction

Cooperative vocational education offers many advantages in preparing young people for employment. For example, students with cooperative experience have networks for finding jobs, earn a higher starting salary than their counterparts without cooperative experience (Taylor, 1988), and can obtain three benefits: career development, career progress, and personal growth (Fletcher, 1989). However, there are many elements in cooperative programs that are keys to success — talented students, qualified employers, related jobs and good faculty (Laycock *et al.*, 1991). The purpose of this study was to identify contributions of cooperative vocational education to students and relationships with components of employers' implementation as perceived by involved teachers, students and graduates. Components of employers' implementation which influenced contributions of cooperative programs could then be used as the criteria to select cooperative employers.

II. Method

1. Sample

Samples used in this study were selected from teachers, students and graduates who were involved in the cooperative programs. There were 57 senior high schools which had cooperative programs in 1991. Samples were randomly selected from these schools. 6 teachers, 10 students, and 12 graduates were randomly selected from each school for the study, that is, there were 342 teachers, 570 students, and 684 graduates involved in the study.

2. Instruments

The survey instrument was developed through the following steps:

(1) Review of related literature.
(2) Interviews with students, teachers, graduates involved in cooperative programs.
(3) Interviews with experts of cooperative vocational education.
(4) Construction of the preliminary questionnaire: Contributions of cooperative vocational education were evaluated by 3 components: economy (8 items), skill (6 items), and attitude (9 items); employers' implementation was evaluated by 5 components: training (10 items), employers' guidance (6 items), work environment (9 items), equipment (4 items), and compensation and fringe benefits (8 items). There was a total of 60 items in the questionnaire; each item was evaluated on a four-point rating scale.
(5) Pilot test: the instrument was pilot tested with 5 teachers, 8 graduates, 40 students, and 5 experts for validation.
(6) Test and retest: 120 students were randomly selected from three schools to be tested and retested with a three-week interval for test-retest reliability.
(7) Item analysis: the correlation coefficient between items and related components was used to determine if items were retained or deleted. Those items which had a correlation coefficient significantly below 0.001 were deleted. One item was deleted in components of economy and employers' guidance. A total of 58 items was retained in the survey instrument.

3. Validity and reliability

(1) Validity

The instrument was pilot tested by teachers, students, graduates, and experts to ensure its content validity and clarity. The discriminating power of items was tested by item analysis.

(2) Reliability

Cronbach's alpha was used to indicate the reliability of components of the instrument. The results are listed in Table 1.

The coefficient of stability was obtained through the test-retest method; the results are listed in Table 2.

Table 1. Reliability of Internal Components

Components	Cronbach's alpha (n = 116)
Training	.786
Employers' guidance	.685
Work environment	.697
Compensation and fringe benefits	.636
Equipment	.730
Economy	.782
Skill	.727
Attitude	.721
Total	.92

Table 2. Test-Retest Reliablility

Components	Coefficient of reliablility
Training	.55
Employers' guidance	.51
Work environment	.62
Compensation and fringe benefits	.75
Equipment	.51
Economy	.74
Skill	.51
Attitude	.56
Total	.66

4. Data Collection

Instruments were sent to the director of the cooperative program of each school; the director was asked to forward the questionnaires to teachers, students, and graduates.

Teachers' and students' questionnaires were then collected and sent back to the researcher by directors of cooperative programs; graduates' questionnaires were sent back directly by graduates.

Out of 342 questionnaires sent to teachers, 210 were returned; this gave a return rate of 61.4 percent. Out of 570 questionnaires sent to students, 381 were returned; this gave a return rate of 66.8 percent. Out of 684 questionnaires sent to graduates, 145 were returned; this gave a return rate of 21.2 percent.

5. Statistical analysis

Data were analyzed by using the SPSSx package. There were 4 statistical methods used to analyze data. These were: mean, standard deviation, one-way ANOVA, and stepwise multiple regression.

III. Results

1. Contributions of cooperative programs

The mean and standard deviation of each component for contributions of cooperative programs are shown in Table 3. The mean values for contributions of cooperative programs ranged from 2.53 to 3.07. These indicated that cooperative programs were contributory to these components as perceived by teachers, students, and graduates. However, the results of the analysis of variance indicated that the mean ratings of each component as perceived by teachers, students, and graduates were significantly different at the .05 level (see Table 4). In general, Teachers had higher mean ratings than graduates and students, graduates had higher mean ratings than students.

2. Employers' implementation

The mean and standard deviation of each component of employers' implementation are shown in Table 5. The mean values for components of employers' implementation ranged from 2.23 to 3.02. In general, teachers and graduates agreed that employers offered good services in all components (M>2.48); students didn't think so. In all components, compensation and fringe benefits had lowest values rated by all subjects. The results of the analysis of variance indicated that the mean ratings of each component as perceived by the subjects were significantly different at .05 level (see Table 6). Teachers had higher mean ratings than graduates and students; graduates had higher ratings than students.

Table 3. Contributions of Cooperative Programs

Components	Teachers		Students		Graduates	
	M	SD	M	SD	M	SD
Economy	2.90	.40	2.53	.55	2.71	.52
Skill	3.00	.45	2.73	.48	2.92	.38
Attitude	3.07	.39	2.90	.37	3.04	.34

Table 5. Components of Employers' Implementation

Components	Teachers		Students		Graduates	
	M	SD	M	SD	M	SD
Training	2.86	.50	2.49	.60	2.65	.45
Employers' guidance	3.02	.38	2.47	.63	2.88	.55
Work environment	2.96	.42	2.40	.59	2.59	.50
Compensation and fringe benefits	2.85	.48	2.23	.62	2.48	.58
Equipment	2.98	.42	2.44	.61	2.66	.51

3. Predictions

Regression results revealed that 4 components of employers' implementation were strong predictors of contributions of cooperative programs (see Table 7). These components were training, work environment, equipment, and compensation and fringe benefits. 55 percent of the variance in contributions of cooperative programs was explained by these components.

IV. Conclusions and Recommendations

The conclusions drawn in this section were based on the results of this study.

1. Teachers, students, and graduates agreed that cooperative education was a contributory program to students. However, the mean ratings were not

Table 4. Analysis of Variance for Contributions of Cooperative Programs

Components	Source	D.F.	S.S.	M.S.	F ratio	Scheffè's comparisons
Economy	Between groups	2	15.62	8.26	31.03*	Teachers > Students Teachers > Graduates Graduates > Students
	Within groups	658	175.20	.27		
Skill	Between groups	2	10.45	5.22	25.41*	Teachers > Students Graduates > Students
	Within groups	667	137.14	.21		
Attitude	Between groups	2	17.18	8.59	28.87*	Teachers > Students Graduates > Students
	Within groups	660	196.37	.30		

*$P < .05$

Table 6. Analysis of Variance for Components of Employers' Implementation

Components	Source	D.F.	S.S.	M.S.	F ratio	Scheffè's comparisons
Training	Between groups	2	17.18	8.59	28.87*	Teachers > Students Graduates > Students Teachers > Graduates
	Within groups	660	196.37	.30		
Employers' guidance	Between groups	2	36.47	18.24	60.87*	Teachers > Students Graduates > Students Teachers > Graduates
	Within groups	662	198.31	.30		
Work environment	Between groups	2	36.96	18.48	65.78*	Teachers > Students Graduates > Students Teachers > Graduates
	Within groups	642	180.37	.28		
Compensation and fringe	Between groups	2	44.66	22.33	67.34*	Teachers > Students Graduates > Students Teachers > Graduates
	Within groups	635	210.56	.33		
Equipment	Between groups	2	35.25	17.62	58.77*	Teachers > Students Graduates > Students Teachers > Graduates
	Within groups	657	197.02	.30		

* $P < .05$

Table 7. Regression Results of Components of Employers' Implementation to Contributions of Cooperative Programs

Step	Components	R	R^2	B	Beta	F
1	Training	.69	.48	.22	.32	519.93*
2	Work environment	.73	.54	.12	.17	334.16*
3	Equipment	.74	.55	.13	.20	236.48*
4	Compensation and fringe benefits	.75	.55	.10	.16	148.81*

* $P < .05$

very high ($M < 3.07$); there were significant differences among their perceptions.

2. Teachers agreed that employers offered contributory programs to students; graduates agreed that employers offered contributory programs to students except compensation and fringe benefits; students didn't agree that employers offered contributory programs to them.
3. Training, work environment, equipment, and compensation and fringe benefits were strong predictors for contributions of cooperative programs. 55 percent of the variance could be explained by these components.

The following recommendations were made based on the results and conclusions of this study:

1. Contributions of cooperative programs needed to be advanced, since the mean ratings were not high enough.
2. The differences in contributions of the program and components of employers' implementation as perceived by the subjects needed to be further studied.
3. The components of employers' implementation were strong predictors for contributions of cooperative programs. These components could be used as the criteria for selection of cooperative employers.
4. Employers might need to offer better compensation and fringe benefits.

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I appreciate the financial support of the R.O.C. National Science Council under grant number NSC 81-0111-S-018-06.

References

Fletcher, J.K. (1980). Student outcomes: What do we know and how do we know it? *Journal of Cooperative Education, 26*(1), 26-38.

Laycock, A.B., Hermon, M.V. & Laetz, V. (1990). Co-operative education: Key factors related to a quality experience. *Journal of Cooperative Education 27*(3), 36-46.

Taylor, M.S. (1988). Effects of college internships on individual participants. *Journal of Applied Psychology, 73*(3), 393-401.

職業學校建教合作教育對學生之實施效益及其與合作廠商執行要素相關之研究

蕭 錫 錡

國立彰化師範大學工業教育研究所

摘　要

本研究主要在探討職業學校建教合作教育對學生實施效益及其與合作廠商執行要素相關之研究。研究樣本隨機取樣自職業學校建教合作教育有關之教師324人，學生570人，和畢業生684人。本研究資料係透過問卷調查方式收集。

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Cognitive Development of the Concepts of Linear Function and Quadratic Function for Junior High School Students

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ABSTRACT

The function concept is, without doubt, one of the most fundamental in all mathematics and one of which students seldom develop a satisfactory understanding. In accordance with Piaget's idea that the most elementary function concept developed in a child's mind can be considered as a relation between the magnitude of two quantities, the variation in one bringing about the variation in the other in the same proportion, it can be seen that the first emergence of function concept is linear. In fact, the concepts of linear function as well as quadratic function play an important role in Taiwan's junior high school mathematics curriculum. If students grasp these concepts, their future study of mathematics is eased.

The primary goal of this research is to collect information about the cognitive development of the concept of functions for junior high school students in Taiwan. The study was an attempt to measure the extent to which the concept of a function had been mastered. Precisely, the aim of the research was to study the possibility of finding out both how the concepts of linear function and quadratic function were developed and how they were learned. With this in view, we particularly tried to work out the genetic decomposition of these concepts and provide an appropriate cognitive model of them.

Key words: *linear function, quadratic function, genetic decomposition*

I. Introduction

Like the concepts of integer, fraction, ratio, and variable, the function concept is one of the most fundamental and central topics in all mathematics. But by the end of 19th century, most mathematics teachers were convinced that the most essential skills in junior high school mathematics courses were those of manipulating algebraic operations. On the other hand, the concept of function was regarded as unimportant. Nowadays, the junior high school mathematics curriculum relies heavily on the concept of function. There are two major reasons for this great adjustment:

1. It is realized that the function concept can be used to tie together seemingly unrelated mathematical concepts, such as those in algebra, geometry, analysis, etc.

The research reported in this paper was supported by the National Science Council, Republic of China, under grant NSC 81-011-S-003-30-A.

2. The function concept plays an important role in physics. Many of its problems can be solved by using the concept of function. Therefore, the demand for knowledge of the function concept in the junior high school mathematics curriculum has naturally arisen.

The concept of function is usually introduced in one or several of a variety of representations, either simultaneously or in short succession. Those representations include graphs, arrow diagrams, tables, algebraic formulas, word problems, and ordered pairs. The same function is taught by different means in each of these representations. The question then naturally arises whether students establish appropriate links between the different representations of the same function. More often, it is well-known that most junior high school students have difficulties in learning the function concept, such as the translation of the graphical representation of a function either parallel to the vertical axis or the horizontal axis. The effect of the first transformation is seen to be vertical translation:

$$f(x) \rightarrow f(x)+k$$

while the effect of the second transformation is horizontal translation:

$$f(x) \rightarrow f(x+k)$$

In order to understand translation of functions, students should first encapsulate the function f(x) as being an object, and then move the object k unit(s) according to the direction specified.

There is a considerable amount of research on the nature and learning of the function concept (Dreyfus & Eisenberg, 1987; Dreyfus & Vinner, 1982; Kleiner, 1989; Law, 1993b; Lovell, 1971; Nitsa, 1988; Schwartz & Dreyfus, 1989; Vinner & Dreyfus, 1989; Yen & Law, 1992). Some focused on its algebraic representation and set representation (Dreyfus, 1982; Janvier, 1982; Sfard, 1989). Bergeron and Herscovics (1982) identified different stages in the building of the notion of function which consisted of four levels of understanding: (1) intuitive understanding; (2) initial mathematization; (3) abstraction; and (4) formalization. Breidenbach *et al.* (1992) claimed that understanding of the function concept required a well-developed internal mental process that transformed an object into another object, and working with computers in certain ways seemed to have a good effect on students' abilities to construct this mental process. Dreyfus and Eisenberg (1982) assessed the intuition students had about function concepts presented in diagram, graph, and table settings. Markovits *et al.* (1986) investigated the level of understanding and difficulties of the function concept for junior high school students. In October 1990, a conference was held in West Lafayette with discussions about the concept of function from both epistemological and pedagogical points of view, what it means to learn the concept of function and how instruction based on research can help. A group of mathematical education researchers from all over the world, who had done and are doing important work on the concept of function, participated in the conference. Several major themes emerged. They were: conceptions and misconceptions of function held by students and teachers; research methodology; empirical investigations and teaching practice; the use of computers.

The study, by Piaget *et al.* (1968; 1975), dealt with the growth of understanding of some aspects of the concept of function. For Piaget and his colleagues, the establishment of function concept from constitutive or preoperatory functions into constituted functions and operations required a period of years. With respect to the schema of ordered dependences, they claimed that the function concept emerged between four and seven years of age. Furthermore, they showed how often the schema of proportionality had been linked closely to the elaboration of constituted functions. In accordance with the study that the most elementary function concept developed in a child's mind can be considered as a relation between the magnitude of two quantities, the variation in one bringing about the variation in the other in the same proportion, it can be seen that the first emergence of function concept in a child's mind is the concept of linear function. In fact, the concepts of linear function as well as quadratic function play an important role in the Taiwan junior high school mathematics curriculum. If students can grasp these concepts, their future study of mathematics is eased.

The primary goal of this research was to collect information about the cognitive development of the concept of functions for junior high school students in Taiwan. The study was an attempt to measure the extent to which the concept of a function had been mastered. Precisely, our aim was to study both how the concepts of linear function and quadratic function were developed and how they were learned. With this in view, we particularly tried to work out the genetic decomposition of these concepts and provide an appropriate cognitive model of them.

II. Methods

For grades 1-12 in Taiwan, the government invited a panel of experts including junior high and higher school teachers, psychologists, and mathematicians to design a set of standard textbooks for students in a typical school setting. Junior high school students in each grade have to use the same textbook. Therefore, in Taiwan, it is believed that the notion of function is first formally introduced in the eighth grade in abstract form. Students are given examples of the notion of function as a relationship between variable magnitudes. At the same time, the concept of linear function is being taught in the eighth grade. It is not until the 9th-grade that students are introduced to the idea of the quadratic functions, which draw upon knowledge of linear functions.

1. Subjects

The subjects involved in this research were students from ten randomly chosen junior high schools in the Taipei area, five from downtown and the others from the suburbs. For every school participating, we chose one class randomly from each seventh, eighth, and ninth grade. Then four students were picked randomly from each selected class. Thus, there were 40 seventh-grade, 40 eighth-grade, and 40 ninth-grade students in the study sample. This gave us a total of 120 subjects.

2. Instruments

A questionnaire booklet was designed to examine how students handled problems of linear function and quadratic function. Problems followed the guidelines of the teaching-objectives described in the instructor's resource book which were written by the mathematics curriculum committee. In Piaget's view, the function concept emerges between four and seven years of age. We, therefore, had paid attention to the resources of the function concept in the primary-school curriculum when we designed the questions. Additionally, the wording of each question was very carefully scrutinized. And the questionnaire booklet was given to and reviewed by experts, mathematicians, editors of the mathematics curriculum and mathematics educators. After thorough consideration, the questionnaire booklet was revised according to their suggestions.

In this study, students were to learn:

(1) To evaluate f(a) for a given linear function or quadratic function f(x), and a fixed $x = a$.

(2) To describe and understand the meaning of the graph of a function. Specifically, for a given linear function or quadratic function $y = f(x)$, to learn that the graph of $y = f(x)$ is constructed by all the points (x, f(x)) in the plane.

(3) To draw the graph of a linear function or quadratic function. Specifically, for a given linear function or quadratic function $y = f(x)$, to create a table, plot the points, and connect those points with a smooth curve in order to draw the graph of $y = f(x)$ in the plane.

(4) To apply the concept of translation to draw the graph of a linear function or quadratic function. Specifically, for a given linear function or quadratic function $y = f(x)$, to apply the concept of translation to draw the graph of $y = f(x+h)+k$ exactly in the plane.

(5) To understand the characteristics of the values a, h, and k which make up the graph of a quadratic function $f(x) = a(x\text{-}h)^2+k$.

(6) To find out the maximum or minimum value of a quadratic function and understand its properties, especially the symmetrical property of a quadratic function along the vertical line passing through the vertex point.

3. Procedures

After the related materials were covered, the questionnaire booklet was administered to all students in the study sample (Asher, 1976). In order to determine the students' understanding of the concept in detail, some subjects were chosen and interviewed individually to answer the questions again. The whole period of each interview was recorded and later transcribed. Since the purpose of the study was to find how the concepts of linear function and quadratic function were developed and how they were learned, a cognitive conflict was recognized when subjects were unaware of their mistakes. Hints were given to the students to determine how far they were able to go in the development of the concept.

III. Results

The results of the interviews were analyzed by using the method of content analysis (Kerlinger, 1986). The universe of content in the study was subjects' answers in the questionnaire booklet and all the oral replies to the questions. Based on our understanding of the concept and our analysis of the data, the cognitive developments of the linear and quadratic function schemata in our study were divided into four levels which represented one of the possible ways to learn the concepts. These levels were classified as: Level I, *Evaluation of functions*; Level II, *Substitution of expressions*; Level III, *Plotting graphs*; and Level IV, *Understanding quadratic functions*.

The unit of analysis was themes which could be placed under one of the above levels. In order to establish reliable coding, operational definitions were necessary. The theme that was assigned to Level I was evidence that, given a function f(x) and a fixed number a, the subject should be able to evaluate the value of f(a) successfully.

For substitution of an expression into a function, there are two successive stages which are different in difficulty. One is substitution of a symbol, and the other is substitution of an expression in which both symbols and numbers are included. So, in Level II, the subjects should be able to substitute both symbol and expression into some given functions correctly.

For a function, in order to draw its graph in the plane, one should evaluate the function at several x, plot the points (x, f(x)) in the plane, and connect those points with a smooth curve in order to draw the graph of the function. Therefore, when one utilized this approach to draw the graph of a function correctly, one was classified in Level III.

There are several important concepts of quadratic function embedded in the junior high school mathematics curriculum in Taiwan: (a) the concept of translation of the graph of a function; (b) the concept of understanding the meaning of the graph of a function; (c) the concept of understanding the effects of the values a, h, and k which make up the graph of a function $f(x)=a(x-h)^2+k$; and (d) the concept of extreme value and the symmetrical property of quadratic function along the vertical line passing through the vertex point. Overall, if one understood the four concepts stated above, one was put into Level IV. So, according to these four concepts, we divided Level IV into four sublevels: Level IV A, Level IV B, Level IV C, and Level IV D. If a subject could clearly explain how to translate the graph of a function horizontally and vertically as well as their combination, the subject was classified as understanding the concept of translation and put into Level IV A. For a given graph of y = f(x), if a subject understood that the graph was constructed by all the points (x, f(x)) in the plane and was able to use the concept to solve some problems, he or she was classified as understanding the meaning of the graph of a function and put into Level IV B. Given a description of a quadratic function, if one was able to transform it to $f(x) = a(x-h)^2+k$, and explain how to determine the domains of the a, h, and k, then one was classified as understanding the effects of those values in making up the graph of a quadratic function and put into Level IV C. Finally, there was no doubt that more than half of the Taiwan junior-high-school students were good at symbolic manipulation. In fact, when they drew the graph of a quadratic function, we could always see that they used the complete square method to get the vertex point first. So, we focused on the symmetrical property of quadratic function. Thus, if a subject knew the symmetrical property of quadratic function along the vertical line passing through the vertex point, and was able to use it to solve problems, the subject was classified as understanding that concept and put into Level IV D.

1. Level I

The students that were assigned to Level I were those who could evaluate a function at a given point. About 80% of the sample subjects were on this level, since the evaluation of a function at a particular point is no more than the knowledge of what the notion f(a) means and the skills of manipulating algebraic operations. Since, as stated above, the Taiwan junior high school students were good at symbolic manipulation, it was not surprising to have such good results.

Let us quote the responses of a subject, S1, who could not find the value of f(3) when the function f(x) = x + 13 was given. Notice that S1 could find the value of a + 7 if a = 6. It indicated that S1 could handle algebraic operations, but the notion of f(a) was meaningless to him.

Q	Can you tell me why the answer of a + 7 is 13 when a is equal to 6?
S1	It told us that a = 6. So, a + 7 is equal to 6 + 7 and the result is 13.
Q	How about the value of f(3) if f(x) = x + 13?
S1	(No response)

When we asked S1 about what a function was, he answered that a function was an algebraic expression, with unknowns and some algebraic operations. Of course, we could not conclude that he knew the function notion from such a general response. When we went further to ask him about the concept of function, we finally had an astonishing answer "no one ever told me that it was a function."

Q	Can you give me an example of a function?
S1	(No response)
Q	Can you give me an example of a relationship between x and y? That means something with x and y.
S1	(He writes x + y = 27 on a paper.)
Q	If we change it to the form f(x) = y = 27 − x, then is it a function?

S1	I think it is, but no one ever told me that it was a function.

In the second excerpt, there was a student, S2, who was in Level I since he could answer the question of how to evaluate a function correctly. Although he gave the right answer, to substitute a symbol, he still made a mistake when he was asked to substitute an expression. We could see that what he had done was simply to put the expression a + 2 into the function f(x) = 6x-8. And, he got an answer 6a + 2-8 which became 6a-6. It showed that he did the substitution of an expression as if he was in the action stage. Thus, he was not fully in Level II.

Q	What is the answer of f(t) if f(x) = -2x + 3?
S2	Well, if f(x) = -2x + 3, then, we can change x to t and get f(t) = -2t + 3.
Q	That's very good. What is the answer of f(a + 2) if f(x) = 6x-8?
S2	Do the same thing like substitution of x with a + 2.
Q	And then, what is your answer?
S2	6a-6.

2. *Level II*

The subjects in Level II could correctly substitute both symbol and expression into some given functions. In order to substitute an expression into a function correctly, one should encapsulate the expression as an entity, make the process of substituting the object into the function, and then de-encapsulate the object back to a process, and finally do the algebraic operations to get the answer. We had a subject, S3, who had a good concept of how to substitute expressions. When she was asked to substitute a symbol and expression, her response was as follows:

Q	What is the answer of f(t) if f(x) = − 2x + 3?
S3	Substitute t for x.
Q	Well, do you mean that you replace all the x's by t's?
S3	We have the same x on both sides. So, if you replace the x on one side, then you ought to replace the x on the other side. Like the previous question of asking the value of f(3), if you replace the x with 3 on one side, then the other side will become 3 + 13.
Q	Well, how about the answer of f(a + 2) if f(x) = 6x−8?
S3	6a + 4.
Q	How did you get it?
S3	(She writes 6(a + 2) − 8 = 6a + 4.)

From her responses, we could see that when she replaced the x with the number 3, or the symbol t, or the expression a + 2, she encapsulated them each as one entire object. After she went through the process of substituting the object into the function, the answer 6(a + 2)-8 shows that she de-encapsulated the object back to a process, and finally she interiorized the process of the function to get the answer.

On the other hand, she was not on Level III. This was supported by her responses to questions. As illustrated below, her answers were indefinite, and she kept silent several times.

Q	Can you give me an example of a function?
S3	(Silence)
Q	You can show me a graph of a function or write it down.
S3	I don't know.
Q	Well, can you draw the graph of 3x + 2y = 6?
S3	(She draws a straight line.) Is it right?
Q	What do you think?
S3	(Silence)
Q	How about the graph of $f(x) = x^2 + 2$?
S3	I don't know how to draw it.

3. *Level III*

For a function, in order to draw its graph in the plane, one should evaluate the function at several x's, plot the points (x,f(x)) in the plane, and connect those points with a smooth curve in order to get the graph of the function. Therefore, when one utilized this approach to draw the graph of a function correctly, one was classified in Level III. If students understand the concept behind this approach, they can draw the graph of many functions, particularly the graph of linear and quadratic functions. But, observing some junior high school students in Taiwan as they tried to draw the graph of linear or quadratic functions, we found that they did the problem a little differently. We would like to discuss two subjects, S4 and S5, to reveal the difference. S4 was not in Level III, and S5 showed his understanding of the concept of plotting a graph.

When S4 drew the graph of a linear function, she only plotted two points in the plane, and used a ruler to connect those points in order to draw a straight line. When she was asked "why do you choose two points only?", her response showed that she did not understand the concept of plotting a graph. What she had done were only the mechanical actions.

Q Can you draw the graph of $3x + 2y = 6$?
S4 (She finds two points (2, 0) and (0, 3), plots them on the plane, and connects them to draw a line.)
Q Well, you found two points only, and connected them to get a line. Why do you choose two points only? How do you know that two points are O.K.?
S4 Because it is the answer.
Q Is it better to find some more points?
S4 (No response)
Q Did you teacher tell you that two points are O.K.?
S4 Yes.
Q Have you any doubt about what your teacher said?
S4 No.

The interviewer continued to ask her to draw the graph of a quadratic function in order to check her understanding of the concept of plotting a graph. But she still showed her inadequacy.

Q Can you draw the graph of $f(x) = x^2 + 2$?
S4 I don't know how to draw it.

Although S5 drew a straight line by connecting two points only, she did understand the concept of plotting a graph. The conclusion came from her response to the interviewer's question in drawing the graph of a quadratic function.

Q Can you draw the graph of $2x + 3y = 6$?
S5 (She draws it.)
Q Well, I saw that you found two points only, and connected them to get the line. Why do you choose two points only? How do you know that two points are O.K.?
S5 It is because using two points is the easiest method to draw a line.
Q Is it better to find some more points?
S5 Of course it is.
Q You know that it is better to have more points, then why you don't use more points to draw a line.
S5 It is because they still lie on the same line.
Q Can you draw the graph of $f(x) = x^2 + x - 2$?
S5 (She finds the minimum point $(-1/2, -9/4)$ by using the complete square method, and then evaluates the function at $x = -3/2, 1/2, -5/2, 3/2$.)
Q You found the minimum point first. Well, why did you evaluate the function at those values of x?
S5 It is because $-3/2 = -1/2-1$, $1/2 = -1/2+1$, $-5/2 = -1/2-2$, and $3/2 = -1/2+2$.
Q I see. You try to find. . . .
S5 A symmetric graph.
Q Why do you choose so many points this time? Is it possible to select fewer?
S5 If I choose three points, it is hard for me to draw a quadratic function.

From the above excerpts, we can see that most Taiwan junior high school students use two points to draw the graph of a linear function, and they try to find the extreme point of a quadratic function first when they are asked to draw the graph. There is no doubt that the above method is the most convenient and efficient way to draw such graphs. But we think that it is better for students to develop the concept of plotting a graph before teaching them the above efficient drawing method.

4. Level IV

There are four important concepts of quadratic function in the junior-high-school-mathematics curriculum in Taiwan. According to these concepts, we divided Level IV into four sublevels. In Level IV A, we offered the function $f(x) = x^2$ and presented its graph. We asked three questions. In the first question, we gave students the graphs of $y = (x + 1)^2$, $y = (x - 1)^2$, $y = x^2 - 1$, and $y = x^2 + 1$ without equations of those functions. We also provided the coordinates of the minimum point in each graph. Students were asked to pick the graph of $y = f(x) + 1$ from these four graphs. In the second question, we gave students the graphs of $y = (x + 4)^2$, $y = (x - 4)^2$, $y = x^2 - 4$, and $y = x^2 + 4$ without equations of those functions. We also provided the coordinates of the minimum points as well. Students were asked to pick the graph of $y = f(x + 4)$ from these four graphs. In the third question, we gave students the graphs of $y = (x - 6)^2-3$, $y = (x + 6)^2 - 3$, $y = (x - 6)^2 + 3$, and $y = (x + 6)^2 + 3$ without equations of those functions either. Also, the coordinates of each minimum point were provided. Students were asked to pick the graph of $y = f(x - 6) - 3$ from these four graphs.

From observations of students as they tried to answer these three questions, we found a common problem: most students substituted the minimum point into the given function to check which one was the answer, or they simplified the given equation of the function to help them determine the answer. Of course, substituting a point into the given function was a good method to find the answer. But it conflicted with our purpose of obtaining some ideas about students' understanding of the translation concept. In order to prevent this from happening again, we recommended not giving the coordination of the minimum point next time. Certainly it was not reasonable, at this point, to conclude that students did not understand the concept of translation. We must have further investigation to test their knowledge of this topic.

In the excerpt, there was a subject, S6, who could find the correct answer of the first question by substitution. But actually, she made a mistake in the second question. It indicated that she had trouble substituting a point into a function like $y = f(x + a)$. In addition, she did not possess the schema of translation concept.

Q	How did you choose this graph ($y = x^2 + 1$) as the answer to the first question ($y = f(x) + 1$)?
S6	I put the minimum points into the equation.
Q	Have you learned the concept of translation?
S6	Yes.
Q	How do you choose this graph ($y = (x - 4)^2$) as the answer of the second question ($y = f(x + 4)$)?
S6	I don't know how to do it.

In the second excerpt, there was a subject, S7, who could find the correct answers of all three questions. In the questionnaire booklet, we could see that he simplified the functions and made tables of those functions. But actually, we could see that he still found the minimum point of each function. As shown in the following dialogue, although the interviewer challenged his understanding of the concept, he still showed that he possessed the schema of the concept.

Q	Well, did you check the minimum point of the function in order to find the answer?
S7	Yes.
Q	Can you use the concept of translation to find out the answer?
S7	Can you explain it clearly?
Q	I mean can you move this graph ($y = x^2$) in order to get the graph of $y = f(x) + 1$?
S7	You mean move the original graph directly to get the answer.
Q	Right.
S7	O.K. I understand. Do you want me to do some problems?
Q	Of course. If we have a graph of $y = f(x)$ in here, no matter which one, can you tell how to find the graph of $y = f(x + 2)$?
S7	Move it to the left.
Q	To the left, why?
S7	I don't know how to say it. . . . Since 2 is inside the bracket, no matter if x is positive or negative, $x + 2$ (he is talking about the function $y = f(x + 2)$) has the same y as x in the first graph ($y = f(x)$). So, the x in the second equation ($y = f(x + 2)$) should be smaller than the x in the first equation ($y = f(x)$). Therefore, I move it to the left 2 units.
Q	Well, how about $y = f(x) + 2$?
S7	It should be moved two units upward. It is because the y in the second equation ($y = f(x) + 2$) is greater than the y in the first equation ($y = f(x)$) with respect to the same x.
Q	Well, that is very good. Then how about $y = f(x - 1) + 3$?
S7	Move right one unit, and then move upward 3 units.

Let us discuss the conversation in detail since it told us much about the cognitive process of understanding the translation concept. After the interviewer explained the meaning of translation, S7 was required to do some problems. We can see that S7 is a very active student. When the interviewer challenged his answer 'to the left' of the first question, he struggled a lot to express his thinking. (To clarify the x in these two functions, we write t for x in the second function.) S7 first recognized that $t + 2$ in the second function $y = f(t + 2)$ has the same value of y as x in the first function $y = f(x)$. That means he encapsulated $t + 2$ as an object, and compared the values of y in these two functions. It also indicated that he de-encapsulated the graph as a set of points. When he said "the x in the second equation should be smaller than the x in the first equation," it showed that he de-encapsulated the object $t + 2$ back to a process, obtained the equality $t + 2 = x$, and reversed it to $t = x-2$, and finally drew the conclusion that t was smaller than x. As a result, he encapsulated the graph of $y = f(x)$ as one object and moved it 2 units left. Furthermore, when he was asked the question about $y = f(x) + 2$, he first de-encapsulated the graph as points, and then compared the values of y in these two functions with respect to the same x, and finally found out the value of y in the second function was two units bigger than the value of y in the first function. In other words, he encapsulated the graph as an entity and moved it two units upward. From his responses, it was clear that S7 possessed the schema of translation concept firmly.

In level IV B, we draw the graph of a quadratic function $y = f(x)$ $(f(x) = (x+1)(x-3))$ with lines indicating the positions of some points. Students were asked to find the solution sets of $f(x) = 0$ and $f(x) = 5$. It seemed that it was easy for students to find the answer of $f(x) = 0$ since what they needed to do was to find the roots of $f(x)$ from its graph. There is no doubt that if we offer a quadratic equation, most students in Taiwan can solve it and get the correct answer. But, in fact, if we give the graph of a quadratic function and ask students to find the solution set of $f(x) = 0$, it becomes extrinsic. In this setting, students are puzzled and cannot establish the link between an algebraic formula and a graph of the same function. As result, they try to find the answer by guessing. Another common error was that some students viewed the line $y = 0$ as the y-axis and found an incorrect answer. Let us see two excerpts, S8 and S9. When the interviewer asked "can you find the solution set of $f(x) = 0$ from the graph?", S8 replied $x = 0$ by guessing, and S9 viewed the line $y = 0$ as the y-axis and found the intersection point (0, -3) of $f(x)$ and the y-axis. Besides, S9 also was confused with the coordinates of x and y.

Q Well, can you find the solution set of $f(x) = 0$ from the graph?
S8 $x = 0$.
Q My question is the solution set of $f(x) = 0$.
S8 x should be equal to 0.
Q You say $x = 0$, why?
S8 (No response)
Q Well, how about the solution set of $f(x) = 5$?
S8 It should be 5.

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Q Well, can you find the solution set of $f(x) = 0$ from the graph?
S9 We have $x = -3$ when $y = 0$ (he puts his finger at the intersection point (0, -3) of $f(x)$ and y-axis), and I know that $y = f(x)$. Therefore, if $f(x) = 0$, then x should be equal to -3.

Now, let us discuss the response of S10. When he tried to find the answer, his action to draw the line $y = 5$ in his mind showed that he first paid attention to the value of y. This indicates that S10 reversed the process, in which x is given and we try to find the value of y, to the process, in which y is given and we try to find the value(s) of x. S10 then found the intersection points of $y = 5$ and $y = f(x)$. It showed that, at this moment, he viewed the graph of $f(x)$ as all the points $(x, f(x))$. Finally, he got the correct answer, -2 and 4.

Q Well, can you find the solution set of $f(x) = 5$ from the graph?
S10 $y = 5$. It should be these two points.
Q I saw you draw along the line $y = 5$. What were you thinking?
S10 It is the line $y = 5$. In order to find $f(x) = 5$, we should find the intersection points of $y = 5$ and $y = f(x)$. And they are the answer.
Q Well, what is the answer?
S10 -2 and 4.

In Level IV C, we drew four graphs of the quadratic functions: $f(x) = -x(x+4)$; $f(x) = -x(x-4)$; $f(x) = x(x+4)$; and $f(x) = x(x-4)$. We asked students to determine which of the above graphs was the graph of function $f(x) = x(x-b)$, where $b > 0$. There are two ways to solve this problem. One is to transform $f(x) = x(x-b)$ into the form $f(x) = a(x-h)^2 + k$. And then one will find $a > 0$, and vertex (h, k). The other is to figure out the intersection points (0, 0) and (b, 0) of $f(x)$ and x-axis. Moreover, the coefficient of x^2 is 1, thus the answer is obvious. But we found that most Taiwan students prefer to use the first method to find the answer. We interviewed S11 and S12. Although S11 could not give the correct answer the first time, after the interviewer pushed him forward, he was able to develop the concept. Since the excerpt S12 is a quiet girl, the interviewer led her step by step to investigate the concept. We could see that S12 would rather use the first method to get the answer. Guided in use of the second method, she still showed that she could handle the problem.

Q Well, for this question, you gave me two answers (the graphs of $f(x) = x(x+4)$ and $f(x) = x(x-4)$). How did you find these two answers?
S11 I substitute $y = 0$.
Q Substituted $y = 0$?
S11 Yes. It is because any quadratic function will meet the y-axis at one and only one point. Oh, I am sorry. I should substitute $x = 0$ to get the y-intercept.
Q O.K. That is good. But all graphs have intersection with the y-axis.
S11 Then, I check the direction of $f(x)$ (coefficient of x^2). It is upward (>0).
Q So, according to your analysis, you give me two graphs. Right?

S11 Yes.

Q If I tell you that there is only one possible answer, then which one will you choose?

S11 This one (the graph of $f(x) = x(x-4)$).

Q Why?

S11 Because $b > 0$.

Q Can you explain in detail?

S11 The first coordinate of the vertex will be a positive number. Since the first coordinate of the vertex in this graph (($f(x) = x(x-4)$)

Q And then. . . . .

S11 The first coordinate of the vertex will be a positive number. Since the first coordinate of the vertex in this graph (($fx) = x(x-4)$) is a positive number, and negative in that graph ($f(x) = x(x+4)$), I choose this graph as my answer.

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Q For this question, your answer is this one (the graph of $f(x) = x(x-4)$. Why do you choose this graph?

S12 (No response)

Q Well, can you tell me how to determine the direction of a quadratic function?

S12 Check the coefficient of the term x^2?

Q If it is positive, then. . .

S12 It is upward.

Q So, the direction of this function. . .

S12 Upward.

Q If I ask you to find the intersection points of f(x) and the x-axis, then how will you find them?

S12 Use a formula.

Q Formula? Try.

S12 (Uses complete square method to get the vertex.)

Q O.K. What is this point?

S12 The intersection point.

Q Is that correct? The intersection point or the vertex?

S12 Oh, it is the vertex.

Q Then, how do you find the intersection points?

S12 (Writes down $x(x\text{-}b) = 0$.) If you want to find the intersection points, you should let $y = 0$.

Q Then, what is the first coordinate of the intersection points?

S12 0.

Q And. . .

S12 b.

Q So. . .

S12 This graph ($f(x) = x(x\text{-}4)$ is the answer since $b > 0$.

In Level IV D, we plotted the points (-2, 0), (2, 8), (4, 0), and (5, -7) in the plane and told students that these four points lay on the quadratic function $y = f(x)$ ($f(x) = (x+2)(-x+4)$). Students were asked to find the value of c if f(c) was the maximum value of the function. We found that some students used three points to get the equation of the function and then solved for the maximum. If a student used this method, we did not classify him in the Level IV D. Generally, this question was the most difficult problem in the questionnaire booklet, so most students had trouble with it. We discussed the responses of two excerpts, S13 and S14. Although S13 understood the concept of symmetry and got the answer, he still found the equation of f(x) to solve the maximum point (1, 9). And S14, with some help, could solve it by the concept of symmetry.

Q Can you tell me how to find the answer (1, 9) (the vertex point)?

S13 It is because the graph of the quadratic function is symmetric.

Q Then how did you get (1, 9)? I mean how did you use the property of symmetry to get the point (1, 9)?

S13 I found two points (-2, 0) and (4, 0), and their midpoint. . .

Q You found $x = -2$ and $x = 4$, so the midpoint should be $x = 1$. Then how did you get 9?

S13 (No response)

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Q Well, you thought that it was impossible to find the answer. Which message do you think is missing?

S14 The vertex.

Q The vertex! That is the question. O. K. Let us change the method. Why don't you choose $x = 2$ or $x = 5$ as the answer?

S14 Can't imagine that the graph is like that.

Q Well, in your mind, what is the direction of the graph?

S14 Upward. If $x = 2$, then the graph is skewed. That means the graph is not symmetric.

Q O.K. Can you say something about symmetry?

S14 Since the function has two points on the x-axis, if it is symmetrical, then the symmetrical axis should be the line $x = 1$.

Q Very good. Do you know the answer to the question?

S14 No.

30085

Q Can you say something about the vertex and the symmetric axis?
S14 The vertex is in the symmetric axis.
Q If that is true, then what is the x coordinate of the vertex?
S14 Oh! I see. The answer is $x = 1$.

IV. Discussion and Conclusion

The genetic decomposition of linear and quadratic function discussed below depends entirely on Dubinsky's general theory (Dubinsky, 1986, 1991a, 1991b; Law, 1993a), our understanding of the concept, and mainly the protocols of the interviews. The most important information obtained from the protocols was the many explicit examples of the forms of reflective abstraction, which provide the basis for our derivation of the genetic decomposition of the concepts of linear and quadratic function. It is believed that the series of reflective abstractions could be used to construct the concepts of linear and quadratic function. We emphasize that the genetic decomposition illustrated here is not necessarily the only way to decompose these concepts. Also, We suspect that it is not the only way to help students learn the concepts.

1. Genetic decomposition

In the beginning, students should manipulate simple algebraic operations, such as addition, subtraction, multiplication and division of real numbers as well as variables. Moreover, students are expected to know how to simplify an expression. These are the schema (simple algebraic operations) that I assume students possess. Furthermore, I assume that students have the schema of the rectangular coordinate system in two dimensions. Of course, I do not anticipate that junior high school students know much about the rectangular coordinate system. What I expect is that those students will be able to know where the position of a point (a, b) is, and what the values of a and b mean in the plane.

According to the protocols, the first step is to generalize the mental actions of the schema of simple algebraic operations in order to facilitate mental constructions of evaluating functions. For example, supposing that a student is able to find the value of $a+7$ if $a=6$, he can generalize this mental action to the situation of viewing $f(x)=x+7$ as a process of $x+7$ and evaluating $f(6)$ as the value of $x+7$ if $x=6$. The second step is to encapsulate an expression as an object, applying the schema of evaluating a function in order to construct the schema of substitution of expression. At the same time, the schema of plotting graphs can also be developed from both the evaluation of function schema and rectangular coordinate system schema. It is clear that the schemata of substitution of expression and graph plotting are developed in parallel. The latter consists of performing the processes of evaluating several values of function, encapsulating those points $(x, f(x))$ individually as an object, plotting the points in the plane, and connecting them in a smooth curve. Students can coordinate those processes to obtain the schema of graph plotting.

There are four important components for understanding quadratic functions: (a) the schema of translations; (b) the schema of graphs; (c) the schema of coefficients; and (d) the schema of extremes. These four schemata can be developed from the schemata of substitution of expressions and graph plotting. Moreover, they are constructed in parallel too. After the schemata of substitution of expression and graph plotting have been constructed, the student is ready to move on to the construction of these schemata.

The objects of the schema of translation are points and graphs of functions in the plane. Once the student has encapsulated the graph of a function and moved it in some direction, he can construct the schema of translation. For example, when the graph of $y=f(x)$ is given and one is asked to draw the graph of $y=f(x+a)+b$, one can encapsulate $x+a$ as an object, and compare the values of y in these two functions. One needs to recognize that substituting $x+a$ in the second function and then subtracting b, has the same value as substituting x in the first function. Thus, to draw the graph of the second function, one should coordinate these two processes of moving the graph of the first function to the left $|a|$ units, and upward $|b|$ units according to the signs of a and b.

Evaluating functions is always much easier than solving equations. First, one must find the value of y if x is given. This requires manipulating algebraic operations. Second, one must find the value(s) of x if y is provided. It is necessary to reverse the process of evaluating functions. In the case of giving the graph of a function, the difference between these two questions is not too great. The second question can also help to identify whether students understand the concept of a graph. In order to find the answer to the second question, one needs to reverse the process, de-encapsulate the graph as points and then pick the point(s) of the function which satisfies the requirement.

To construct the schema of coefficients, it can be seen that one may experience the effects of coefficients by drawing the graphs of some quadratic functions, and then generalize the result to other quadratic functions. Furthermore, if one can find the vertex of a quadratic function, and realize that its graph is symmetric along the line passing through the vertex, one is ready to build the schema of extreme. Construction of the schema of extreme consists of two reflective abstractions. One is to transform a quadratic function into the form of $f(x) = a(x-h)^2 + k$, and interiorize the process of evaluating $f(h) = k$ as the extreme value of the function. Another is that one should experience the symmetric property of quadratic functions by drawing some graphs, and then generalize the result to construct the schema of extreme. Finally, one is ready to put all of the schemata together and construct the concepts of linear and quadratic functions.

The genetic decompostion of a particular mathematics concept shows how a student can learn it. And it shows an explicit description of possible construction processes between schemata of that concept. We believe that genetic decomposition can help students learn the concept in a meaningful way and thus construct conceptual networks to link their conceptual and empirical knowledge. Therefore, as mathematics teachers, we can use the results to design instructions that can help students follow the construction processes in genetic decomposition and make certain reflective abstractions.

References

Asher, J. W. (1976). *Educational research and evaluation methods.* Boston: Little, Brown.

Bergeron, J., & Herscovics, H. (1982). Levels in understanding of the function concept. In *Proceedings of the Workshop on Functions,* organized by the Foundation for Curriculum Development. Enschede: The Netherlands.

Breidenbach, D., Dubinsky, E., Hawks, J., & Nichols, D. (1992). Development of the process conception of function. *Educational Studies in Mathematics, 23,* 247-28.

Dreyfus, T., & Eisenberg, T. (1982). Intuitive functional concepts: A baseline study on intuition. *Journal for Research in Mathematics Education, 1*(5), 360-380.

Dreyfus, T., & Eisenberg, T. (1987). On the deep structure of function. In J. Bergeron, N. Herscovits, & C. Kerna (Ed.). *Proceedings of the 11th International Conference on the Psychology of Mathematics Education, 1,* 190-196. Montreal, Canada: Universite de Montreal.

Dreyfus, T., & Vinner, S. (1982). Some aspects of function concept in college students and junior high school teachers. *Proceeding of PME VI.* Antwerp.

Dubinsky, E. (1991, a). The constructive aspects of reflective abstraction in advanced mathematics. In Steffe, L. P. (Ed.), *Epistemological foundations on mathematical experiences.* New York: Springer Verleg.

Dubinsky, E. (1991, b). Reflective abstraction in advanced mathematical thinking. In Tall, D. (Ed.), *Advanced mathematical thinking.* London: Riedel.

Dubinsky, E., & Lewin, P. (1986). Reflective abstractive and Mathematics education: The genetic decomposition of induction and compactness. *The Journal of Mathematical Behavior, 5,* 55-92.

Janvier, C. (1982). Approach to the notion of function in relation to set theory. *Proceedings of the Workshop on Functions,* organized by the Foundation for Curriculum Development. Enschede: The Netherlands.

Kerlinger, F. N. (1986). *Foundations of behavioral research* (3rd ed.). New York: Holt, Rinehart and Winston, Inc.

Kleiner, I. (1989). Evolution of the function concept: A brief survey. *College Mathematics Journal, 20,* 283-300.

Law, C. K. (1993a). A genetic decomposition of geometric transformations with an outline of an instructional treatment design through Logo. *Proceedings of the National Science Council, Part D: Mathematics, Science, and Technology Education, 3*(1), 1-13.

Law, C. K. (1993b). Learning the ε-δ definition of continuity. In *Proceedings of the Technology in Mathematics Teaching Conference*, United Kingdom: Birmingham.

Lovell, K. (1971). Some aspects of the growth of the concept of a function. In *Piagetian cognitive development research and mathematics education.* (pp. 12-33). Washington, D. C.: NCTM.

Nitsa, M. (1988). Picturing quadratic functions. In *Proceedings of the Fifth Conference of Israel Computer Using Educators Association.* Israel.

Piaget, J., Grize. J., Szeminska, A., & Bang, V.(1977). The coordination of pairs. In J. Hintikka (ed.), *Epistemology and psychology of function.* (F.X. Castellanos, & V.D. Anderson, Trans.). Mass.: D. Reidel. (Original work published 1968).

Markovits, Z., Eylon, B., & Bruckheimer, M. (1986). Functions today and yesterday. *For the learning of Mathematics, 6*(2), 18-24.

Piaget, J. (1985). *The equilibration of cognitive structures.* (T. Brown, & K.J. Thampy, Trans.). Chicago: University of Chicago. (Original work published 1975).

Schwarz, B. & Dreyfus, T. (1989). Transfer between function representions: A computational model. In G. Vergnard (Ed.), In *Proceedings of the 13th International Conference for the Psychology of Mathematics Education.* Paris, France.

Sfrad, A. (1989). Transition from operational to structural conception: the notion of function revised. In G. Vergnard (Ed.), In *Proceedings of the 13th International Conference for the Psychology of Mathematics Education.* Paris, France.

Vinner, S. & Dreyfus, T. (1989). Images and definitions for the concept of function. *Journal for Research in Mathematics Education, 20*(4), 36-366.

Yen, C. L. & Law, C. K. (1992). *Development of the function concept and instructional treatment design in middle school* (NSC Report No. 81-011-S-003-30-A). Taipei: National Science Council.

國中生函數概念認知發展與教學之研究

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摘　要

函數的概念，在數學領域中佔有十分重要的地位。但學生在學習函數概念時，往往會感到困難。根據皮亞傑研究所得，孩童發展的函數基本概念乃是兩個變量的關係。一個變量的改變，會使另一變量跟隨某一比例而改變。因此，我們認爲孩童最早發展的函數概念是線性函數。事實上，我國國中數學課程中，就包含有線性函數概念以及二次函數概念。若學生能了解此二函數概念，不僅對他目前的學業有所幫助，進一步來說，對他將來學習其他的數學概念也大爲有益。

因此，本研究嘗試探討我國國中生在學習此二函數概念時的認知發展過程。本研究的樣本爲120位國中學生，並根據他們回答問卷的情形，從中抽出30人作面談對象，從而對此二函數概念建立基因分解。

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Factors Influencing Student Utilization of Computational Estimation

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ABSTRACT

This study explores the conceptual development and competence in computational estimation of Chinese students at the elementary school level. In order to achieve this objective, individual interviews were conducted and small group activities concerning estimation were observed. Using the data collected from these observations, conclusions were drawn about the attitudes of students towards computational estimation. Attitudes towards estimation and in-service teachers' experience in estimation were also researched to reflect the possibility of including estimation in future curricula. Fifty-eight teachers and thirty students from 4th through 8th grade participated in this study.

More than half of the teachers consider estimation an important topic and would consider including it in their curriculum. Most students in this study do not use estimation to check their answers on exams or on calculators. Also, many students confuse "Reasonable answer" with "Correct answer".

Key words: estimation, computational estimation, mental calculation, reasonable answers

I. Introduction

This study explores the willingness and situations which together comprise *Estimation*. *Estimation* in our context means mental calculation of an approximate answer to a mathematical question. The study includes two parts. The first part is an observation of students' habits and attitudes with respect to estimation. The second portion collects teachers' attitudes and experiences in regard to estimation.

II. Methods

This study employs the qualitative approach in seeking a better understanding of the conceptual development of estimation. To explore the integration of its teaching and learning, the research design was simultaneously directed at both students and teachers. As a result, this study has two parts. First it presents data regarding estimation concepts prevalent among elementary school students based on observation and interviews.

In the first part, the evaluation of estimation ability is required to understand the estimation concept of elementary school students. However, in certain periods of time, students may seem to rely on estimation for some of their answers, but it cannot be definitively proven that students doing so were in fact using the estimation method of quick and approximate mental calculation; other possibilities cannot be ruled out. To remove these other possibilities, some previous studies (Bestgen *et al.*, 1980; Schoen *et al.*, 1981; R. Reys *et al.*, 1982; B. Reys, 1985) contemplated the use of test questions on transparency sheets or slides, which are then projected on the screen; testees would have to calculate while watching the screen for a few seconds; a new screen would soon follow. This way of testing only allows the testee a very short time to think and reach a reasonable answer by what is hoped to be mental estimation. The learning environment in Taiwan is quite special; under the pressure for admission to higher-quality schools, many students have in fact already learned mental calculation techniques, abacus calculation, and so on. Therefore, if this study used time limits to push students using estimation, then we would not know if they truly used estimation or other means of calculation; this would lead to errors in analysis. Consequently, we decided against using time as a variable, and relied rather on individual interviews and group observations, to see under what circumstances students would use estimation. In addition, we observed student thinking habits, as well as their problem-solving methods and strategies, in order to discover the following:

(1) At what times estimation is utilized by elementary school students to solve problems;
(2) What their willingness, habits, and experience have been regarding estimation;
(3) Their attitudes with respect to estimation.

The second part of this research collects and analyzes the viewpoints, attitudes, and experiences of elementary school teachers. Naturally, teachers are the people who students of elementary school age see most frequently, and they are their major source of knowledge. This deep trust and dependence greatly magnifies the influence of the actions and attitudes of teachers. Hence the need for this research design to also collect teachers' attitudes with respect to estimation and consider the relationship which may exist between these and student attitudes.

1. Research subjects

Children's learning and cognitive abilities increase with age, yet it is not known how their use of and attitudes towards estimation change, though a greater sense of time and its effects seem closely related. Therefore, for comparative purposes, in addition to observing students from fourth to sixth grades, we also collected data from some adults, college students, and junior high school students for reference. Research subjects in this category include two categories:

(1) Group interviews. Subjects were students from third to sixth grade. We worked with six students from each grade, 24 in total, equally split along gender lines. Because our purpose was to observe what non-time-limit-related complexes influence students in the automatic use of estimation, subjects were mainly middle and high level. They also tended to be academic achievers, already possessing basic mathematical ability, and willing to cooperate. All participating students were recommended by their class teachers.

(2) Individual interviews. Subjects included five students in the third grade, six in the fourth grade, ten in the fifth grade, and five in the sixth grade. There were also four eighth-grade students from junior high school, for comparison. The total number of participating students was 30. The fourth grade students were also recommended by their teachers. As part of the process of recommendation, some were selected randomly, by lot. Some were designated. Some were volunteers. Most were middle- or high-level achievers, though overall, none was at the top or the bottom of his or her class.

In the second part of the research, subjects included 58 teachers from four different elementary schools, hereinafter referred to as School A, B, C, and D. School A is located in a city; the others are in suburban neighborhoods.

In addition, eight seniors from a local college and one adult were also studied in order to increase the validity of this research.

2. Research techniques

This research was divided into two parts, with differing research methods. Based on this structure, we designed proper test questions to measure estimation at the elementary school level. The purpose of these questions was not to evaluate the performance of subjects, but to support interview sessions. This may also help in collecting students' responses on estimation questions as we compare the different types of estimation questions with previous studies. Finally, we developed a test(Appendix) for estimation. Questions were drawn according to the level of interviewees. The order of the questions, degree of difficulty, numbers in questions, and quantity of questions, were all changed responsively, depending on the response of interviewees. All questions were written on 15 cm. x 30 cm., cardboard, one question per card.

Despite the estimation questions being used as tools for proceeding with individual interviews, this research also designed estimation activities suitable for groups, so as elicit estimation of numbers by guessing quantities.

In the case of elementary school teachers, we used Questionnaire A, estimation teaching materials, and a Questionnaire B as research instruments. Estimation teaching material(adopted from Y. Chien, 1990) was a 30-40 minute teaching script, briefly explaining the meaning of estimation, estimation strategies, and some examples. Questionnaire A collects general data from teachers, and their attitudes and experience with respect to estimation, prior to their listening to the teaching script; Questionnaire B collects data afterwards. We then compared and analyzed the two different questionnaires to study the change in teachers' attitudes.

3. Proceeding with the research

Our procedure was divided into three parts:

(1) Group observation. In a period of forty minutes, corresponding to the typical elementary school class, groups of five or six students of the same grade were observed to see if estimation could be used by those students to solve real-life problems without been told. The participants were fourth, fifth, and sixth grade students. The groups of fourth and fifth grade students played a weight game, and the six grade played both weight and length games. Audio and video recordings were made of student responses.

(2) Individual interviews. The test of estimation of 30-40 minutes was used for collecting students' answers. Responses were also recorded.

(3) Collecting information on the attitudes and experiences of estimation from teachers, some adults, or students above elementary school level. In the case of recording the responses of elementary school teachers, the order was: questionnaires A; teaching script; and then questionnaires B.

III. Results

1. Regarding students

The observations of students were the following:

(1) Most of the subjects did not have any experience in calculating approximate values. Few had used estimation to check their answers while doing their homework. In testing situations, most simply repeated their calculations; this may be a requirement of their teachers. When they used calculators, they also used the principle of repetition for double-checking, but not estimation.

(2) Even without time pressure, students might still use estimation as long as they were encouraged to. This point may serve as a reference for future estimation testing and teaching materials design. There are some relations between students' willingness to use estimation, and their habits. In this research, students would use their habits of pen calculation, adding by digits, tens, and hundreds, etc., for accuracy. Later it was found that one or two of the students who had a strong inclination to use estimation indicated that their parents habitually encouraged and required them to use the estimation method after calculation, in order to see if their answers were right or wrong.

(3) The use or non-use of the estimation method by interviewees was found to vary with the type of question. Whether their answers were correct or wrong had little to do with their estimation ability. One student can handle different types of questions by using one method. His answers may all be right, but this is not equivalent to saying that his estimation ability is therefore strong. Most of the students used the same method mentioned in earlier studies.

(4) Several phenomena were seen in estimation problems: (a). Use of pen and paper to estimate. (b). Different situations requiring different methods. This kind of student usually possesses a strong feeling for numbers, and seemingly has a stronger tendency to use estimation. (c). Using hands as calculating tools. Some students used fingers to help keep track of carryings. Age did not seem to be a factor predisposing its use.

(5) Based on the interviewees' performance, we can posit the following levels of ability in using estimation: (a) Understanding the meaning of estimation; (b) Knowing when it may be used to solve problems; (c) Being able to make reasonable estimations; (d) Appropriate estimation methods can be used; (e) Can use different estimation methods, depending on the specific features of different numbers in different problems; (f) Can judge among different estimation methods.

(6) Children with stronger number sense may have stronger estimation abilities.

(7) Most students understand the expression "roughly equal to" and can express synonyms such as "more or less equal to", "close to", "might be close to", etc. However, one word bothering them was "reasonable answer". Many children supposed that it meant the correct answer.

2. On the part of teachers it was observed that:

(1) Teachers were all familiar with the differences between estimation and mental calculation.

(2) Most teachers had heard of estimation, but primarily in money applications.

(3) Rounding numbers was the most popular estimation method used by teachers. If teachers discover that there is a method more appropriate, some will adopt it. Most teachers can judge if an estimate is reasonable or not, but one-third cannot, so there seems to be some difficulty with the primary method of estimation.

(4) After listening to the introduction to estimation, all teachers indicated that their way of teaching mathematics would change. Half would change depending on the teaching material; another half would introduce estimation to their students. Over 80% of them thought that estimation had importance in daily life, and supposed that elementary school should include the teaching of estimation. This showed that teachers gave a positive evaluation to estimation.

IV. Conclusion

1. Students can and do estimate in contexts related to their daily habits. The implication of this is that the development of such habits should be encouraged by teachers, through forms as simple as instructing students to doublecheck answers themselves. Such checks are infrequent in the presence of calculators. But few of them check answers if they are done by calculators; they simply breeze through the same calculation or calculate in reverse. This represents one lost opportunity for inculcating such skills, which are particularly appropriate in such situations. Hence successful long-term development of such skills in students must be rooted in teachers, whose encouragement, direction, teaching methods, visible habits, and personal proficiency all can serve to stimulate and sustain student commitment.

2. Even in the absence of time pressure, estimating takes place, especially when we are confronted with familiar numbers in daily life, such as age and cost.

3. Many estimation-related questions were double-checked by mental calculation for correctness, but the data collected indicate that ability in mental calculation across different levels of students is weak. This shows us that while Taiwan students are strong in traditional pen-and-paper calculation ability, even teachers are not always able to use the most appropriate estimation method.

4. This study shows that some teachers' number sense was not fully mature; this may be related to the fact that Taiwan's mathematical education emphasizes a wide variety of mechanical techniques but ignores a deeper, intuitive grasp for numbers.

References

Bestgen, B., Reys, R., Rybolt, J., & Wyatt, J. (1980). Effectiveness of systematic instruction on attitudes and computational estimation skills of pre-service elementary teachers. *Journal for Research in Mathematics Education, 11*, 124-36.

Chien, Y. (1990). The use of self-study material for improving the computational estimation skills of preservice teachers. (Doctoral Dissertation, Teachers College, Columbia Univ., *Dissertation Abstracts International, 51/03A*, 774.

Reys, Barbara B. (1985). Identification and characterization of mental computation algorithms used by seventh and eighth computation exercises. Doctoral Dissertation, Univ. of Missouri-Columbia, *Dissertation Abstracts International, 46/11A*, 3279.

Reys, R., Bestgen, B., Rybolt, J., & Wyatt, J. (1982). Processes used by good computational estimators. *Journal for Research in Mathematics Education, 13*(3), 183-201.

Schoen, H., Friesen, C., Jarrett, J., & Urbatsch, T. (1981). Instruction in estimating solutions of whole number computations. *Journal for Research in Mathematics Education, 12*, 165-78.

Appendix
Test for Estimation

1.
$$\begin{array}{r} 119 \\ 46 \\ 137 \\ 940 \\ +\ 300 \\ \hline 602 \end{array}$$
Is this figure correct?

2.
$$\begin{array}{r} 320 \\ 520 \\ 630 \\ 150 \\ +\ 470 \\ \hline 2081 \end{array}$$
Is this figure correct?

3. $27 \times 3 = 621$ Is this statement correct?

4. Is the result of 46×91 hundreds or thousands?

5.
$$\begin{array}{r} 47 \\ \times\ 9 \\ \hline 423 \end{array} \qquad \begin{array}{r} 98 \\ \times 16 \\ \hline 948 \end{array} \qquad \begin{array}{r} 38 \\ \times 12 \\ \hline 456 \end{array}$$
Which one of above three is incorrect?

6. You press 47×0.28 on a calculator and get 131.6. Is that the correct answer?

7. Which one of the three ① 60 ② 80 ③ 100 is the closest to 1.3×64.3?

8. 10/21, 5/11, 19/40, 16/32, 7/15, 8/14, 5/6, 4/9, 8/16 Which one of the above nine fractions is ① greater than and closest to 1/2 ② less than and closest to 1/2 ③ exactly 1/2?

9. Which of the four numbers ① 1 ② 2 ③ 19 ④ 19/21 is the closest one to $11/12 + 8/9$?

10. Which of $1/2 + 3/4$ and 1 1/2 is the largest?

11.
$$\begin{array}{r} 9378 \\ +\,8154 \\ \hline \end{array}$$
is approximately equal to ① 10000 ② 15000 ③ 20000?

12.
$$\begin{array}{r} 7034 \\ -\,3892 \\ \hline \end{array}$$
is approximately equal to ① 3000 ② 4000 ③ 5000?

13.
$$\begin{array}{r} 51 \\ 49 \\ 52 \\ 50 \\ 48 \\ +\,53 \\ \hline \end{array}$$
What is the approximate answer?

14. $48 + 17 + 64 + 38 = 167$. Does the answer seem correct?

15. 231
4
253
9
+ 12

What is the approximate answer?

16. 78
× 5

The answer is ①tens ②hundreds ③thousands?

17. 210
198
203
204
+ 197

What is the approximate answer?

18. 458
174
649
+ 362

yielded an answer of 1643. Is the answer reasonable?

19. The approximate answer of 7492 + 5315 + 2387 + 4004 is ____________

20. The result of 5,456,860,473
+ 2,384,653,201 is about ____________ .

21. Which of the differences is closest to 500? ① 1098, 896 ② 1275, 257 ③ 1203, 749

22. Your father purchased 25 liters of gasoline at NT.$ 18/liter. How do you pay? ① using a thousand-dollar bill ② using a five-hundred-dollar bill ③ other combination

23. On the face of a calculator when doing 7341 ÷ 9, $\boxed{1037.8889}$ $\boxed{926.7778}$ $\boxed{815.6667}$ which answer is correct?

24. 2559 ÷ 6 is about ① 40 ②400 ③ 4000

25. 214 × 32 is about ① 600 ② 6000 ③ 700 ④ 7000

26. 8.4 × 896 is about ① 750 ② 7500 ③ 75000

27. $\frac{9 \times 17}{35}$ is approximately equal to ___________ .

28. How old are you? ____________ . How many days have you lived? ____________ .

29. You have savings of 600 dollars. Today is Mother's day and there is 30% off the price of a book at NT$ 785. Can you afford to buy the book?

30. 8793 ÷ 42 is approximately equal to ________________ .

31. $\frac{4936}{48}$ is about ① 100 ② 1000 ③ 200 ④ 2000

32. 35000 ÷ 104 is about ① 300 ② 3000 ③ 30000

33. $\frac{4,784,351}{12}$ is about ① 4000 ② 40000 ③ 400000

34. $3950 \div \frac{2}{3}$ is about ① 5000 ② 6000 ③ 7000

35. 29450 ÷ 32 is about ①92.031 ② 920.31 ③ 9203.1

我國國小學童使用估算意願之探討

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摘要

本研究探討影響我國國小學童使用估算的因素及緣由。爲達研究目的，本研究使用個別訪談及小組活動觀察，並配合收集小學教師對估算之態度。

國小學生使用估算的經驗不多，但在受鼓勵的情況下會使用估算來驗算數學答案。許多小朋友將答案是否「合理」認爲是指「正確」的意思。

大部份教師認爲估算是重要的部份，應該要教給學生。

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Microcomputers as Lab Tools in Learning Graphical Representations

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ABSTRACT

This research examines changes in students' graphing skills and scientific concepts brought about by the use of Microcomputer-Based Laboratories (MBL's) as opposed to a traditional learning environment in four seventh-grade classrooms (two standard and two honor classrooms) in New England, U.S.A.

The primary investigations focus on (1) which situation (MBL's or a traditional learning environment) is more effective in improving students' scientific competence, (2) whether gender influences performance, and (3) whether there are systematic differences in student performance that are attributable to differences in academic ability. This study also investigates how teachers and students interact in each experimental setting and how students reflect on their behaviors with the instructional tools. However, in this article, these observations are excluded.

The findings of this research reveal that important predictors of students' performance on the post-test were the level of students' ability and the treatment. Gender was not a significant predictor of the post-test scores. Also, the treatment had the same effect regardless of student ability. The main contribution to the difference between treatment and control group was due to differences on the subtest of distance items. There were no differences between the treatment groups on the subtest of velocity items. In addition, students improved the most on items that required them to translate from graphs to written descriptions. This suggests that experiences in this study helped students to be better graph interpreters. However, they were still incapable of constructing velocity graphs from distance graphs. This was evident both on their post-test performance and on their worksheets.

Key words: *Microcomputer-Based Laboratories (MBL's), graphical representation*

I. Introduction

While educators now consider computer-assisted instruction (CAI) to be an inadequate substitute for other teaching methods, including laboratory work, research shows that the computer can be used very effectively in conjunction with the laboratory in certain clearly defined areas. One of the most promising and innovative developments in science laboratory instruction is the Microcomputer-Based Laboratories (MBL's) (Mokros, 1985). It has been well documented that MBL's have the potential to be a valuable tool through which educators can tap the power of the computer to help learners develop higher level cognitive processes, problem solving, graph interpretation skills, and better scientific concepts (Adams & Schrum, 1988; Brasell, 1987a, 1987b; Kim, 1989; Linn *et al.*, 1987; Linn & Lewis, 1989; Mokros & Tinker, 1987; Nachmias & Linn, 1987; Stein, 1988; Thornton, 1987; Wells & Berger, 1985-6; Zuman & Weinberg, 1988). Therefore, schools are being urged to include MBL's as a regular part of their activities to improve learning in the science environment (Clement *et al.*, 1985; Kirkpatrick, 1987).

This research examines changes in students' graphing skills and scientific concepts brought about by the use of MBL's as opposed to a traditional learning environment in four seventh-grade classrooms (two standard and two honor classrooms) in New England, U.S.A. There were two reasons for choosing seventh graders as my subjects. First, the most complete data available from previous research are for students between seventh and twelfth grades, so I was able to compare my findings with earlier research. Second, by selecting these particular classes, I could ensure that subjects in the sample had a homogeneous social background.

1. Microcomputer-Based Laboratories (MBL's)

MBL's are laboratories where students use computers as laboratory instruments or laboratory partners to facilitate student-directed data acquisition, display, analysis, and exploration of physical phenomena. With MBL probes and software, students can directly measure such physical quantities as motion or temperature. Students can examine their findings immediately as they collect data, by pairing data collection with symbolic representation of the data in a graph or histogram on the computer. Students do not have to wait until hours or days later when the meaning of the measurements may have become unclear. In this way, MBL's combine Dewey's "learning by doing" and "learning by viewing" that helps students to link an immediate dynamic experience to a symbolic and static representation.

There are three main features that distinguish MBL's from traditional laboratories (Mokros & Tinker, 1987). First, they make possible real-time graphing; data are displayed at the same time that they are acquired, one datum point at a time, through graphic representation. In this way, after the MBL experience, graphs are less likely to be seen as static pictures and more likely to be seen as dynamic relationships (Linn *et al.*, 1987).

Second, MBL's offer multiple modalities. They utilize multiple models to teach graphs and scientific concepts. Students have the potential to transfer acquired knowledge of graphs from one domain to another. This transformation of analogy helps students understand complex concepts and links their knowledge base together as a whole. Also, because students differ in their ability to understand and use particular presentations, the representational flexibility of MBL's allows a better match between students and subject matter (ETC, 1988).

Third, MBL's reorganize the way time is spent in laboratories. MBL activities relieve students of the physical labor of taking measurements, performing calculations, and constructing tables and graphs to report their data. The focus of laboratory activities shifts from collecting data to examining and interpreting data (Thornton, 1987). It has been repeatedly shown that students have difficulty managing the part-activities of complex information management or problem-solving tasks (e.g., Brown *et al.*, 1983). MBL's can structurally support students' accomplishment of the subtasks of science inquiry, and students can participate in the whole task of science inquiry without necessarily having to first master all subskills (Hawkins & Pea, 1987). In this case, students have more time and inclination to ask their own "what if" questions and then can get data to clarify the concepts under investigation.

With these features, MBL's are believed to improve cognitive performance and motivation for students from sixth grade through college. In particular, students appear to improve their understanding in three general areas: (1) scientific concepts (Brasell, 1987a; Linn & Lewis, 1989; Stein, 1988; Thornton, 1986; Wiser & Kipman, 1988), (2) graphs as a symbolic representation of these concepts (Adams & Schrum, 1988; Barclay, 1986; Mokros & Tinker, 1987; Thornton, 1987), and (3) basic scientific processes (Kim, 1989; Linn *et al.*, 1987; Nachmias & Linn, 1987; Zuman & Weinberg, 1988).

Yet, with all of these potential uses, the MBL is just emerging in the curriculum of most schools. Many teachers still do not utilize the computer for instruction. Specifically, teachers do not know how scientific concepts and skills can be explained or enhanced by MBL tools, what MBL's can do for students with different academic abilities, and how MBL's can make the instructional system unique to an educational setting. This may interfere with the decision to make MBL's an integral part of the school environment. As Tinker (1985-86) pointed out:

> Many science educators have been disappointed by microcomputers and feel that the burgeoning technology will have little application to science instruction.

Therefore, to investigate the effectiveness of MBL's, we must ask a variety of questions. What kinds of problems do students have with scientific graphs? What do researchers think might improve students' understanding of graphic representations and scientific concepts with MBL's? Finally, how does the MBL affect different levels of students' needs in order to support their learning?

2. *Difficulties with scientific graphs*

Students are taught graphing techniques in school and are assessed on their graphing skills by both standardized and criterion-referenced achievement tests. Few students, however, are able to relate the graphic representation to the appropriate interpretation of data even when they have produced a precise graph (Bestgen, 1980; Shaw *et al.*, 1983; Clement, 1985; McDermott *et al.*, 1983; Tinker & Mokros; 1987). The results of the *Third National Assessment of Educational Progress* indicated that 9 to 13 year-old children have difficulty with high-level thinking skills, such as interpreting graphs and drawing conclusions from graphs (Lindquist *et al.*, 1983). As Weintraub (1967) states, the use of graphic material often does not aid in the understanding and retention of written material because many students simply cannot adequately use graphs.

One possible explanation for this finding is that the traditional laboratory or lecture instruction does not help students to link their own experience with what can be shown on graphs. Real-life experiences and graphic manipulations are not connected in the student's memory. Therefore, these experiences are not related to each other in a learner's knowledge base. Perkins describes this as "fragile knowledge"; students may have several pieces of knowledge but these pieces are independent of each other. In addition, "fragile knowledge" includes knowledge that often is not activated, and is frequently applied incorrectly when it is used (Perkins, 1986).

A second possible reason why previous research has not found strong effects of adjunct visuals might be a lack of instruction in reading graphic materials (Bamberger, 1942). The difficulties that students have with graphs suggests that recent teaching methods may be inadequate. Teachers fail to stress prerequisite skills, such as recognizing the problem, generating scaling axes, verbalizing the phenomena, the ability to make comparisons, etc. Therefore, children have many problems with graphs (McCune & Pearson, 1963). In addition, many students attempt to respond directly from the graph rather than operating on the information contained in the graph (Bestgen, 1980). Thus, a better understanding of students' difficulties with graphs may help researchers construct a better strategy for the teaching and learning of graphing skills.

Another possible explanation is that graphs are not used interactively in many classrooms. Reynolds and Baker (1987) found that presenting information on a computer, particularly in an interactive format, seems to have motivational and attention-keeping characteristics. Piaget argues that when a person is involved in "self-learning" or "true learning", the net consequence is that the individual invents knowledge that is understood. Such learning results in knowledge that generalizes (Hoffmann, 1986).

Providing an environment in which students can interact with graphs and receive immediate feedback may be critical for a student to develop a solid comprehension of graphs. As Anderson pointed out (1990), the amount of time between the action and the feedback is important — an expected relationship, since for feedback to be useful, the action must be active in memory. After a delay, it may be hard to recall just what led to an incorrect result.

Two types of difficulties related to understanding graphs in the physics curriculum of kinematics have been discussed. First, the most frequent graphing misconception seems to be confusion between the slope and height of lines on the graph (Brasell, 1987a; Clement *et al.*, 1986; Price *et al.*, 1974). For instance, consider an object moving at a constant velocity. The graph of velocity versus time has a zero slope and no change in height, while the graph of distance versus time has a non-zero slope and a constant change in height over time. Students easily accept the latter graph as correct, but question the validity of the velocity versus time graph. The reason for this difficulty may be that the distance variable is concrete and the velocity variable is abstract. Such intuitive misconceptions about distance and velocity appear to be stable and resistant to remedy by conventional instruction (Clement, 1985; Halloun & Hestenes, 1985; McDermott, 1982; Minstrell, 1982). The student's intuition may predominate in environments where he or she has not yet learned how to solve the problem or has not yet identified the problem to be solved in the laboratory (Hofstein & Lunetta, 1982).

Second, many students have a tendency to consider the graph as an actual picture rather than as a symbolic representation of information (Barclay, 1986; Clement *et al.*, 1986; Mokros & Tinker, 1987). This kind of misconception is extremely common and accounts for a large proportion of errors on its own. For instance, students have misinterpreted a distance-time graph as a map of a road or have given explanations that are pictorial answers with geometrical descriptions (Brekke, 1987). Research indicates that, even in college, students still demonstrate an image-dominant performance on a graphing task (Clement, 1985). Students' misconceptions do not arise merely from failure to comprehend the concepts but rather from erroneous interpretation based on intuitive perceptions that must be overcome (Linn, 1987).

3. Gender and ability factors

Gender and level of ability are two issues to be considered as factors related to students' achievement in science. The following sections will elaborate their influences in learning processes.

(1) Gender differences in science education

Research indicates that there are two sources of difference in spatial visualization that may make males more successful than females in graphing skills (Peterson & Schramm, 1954; Strickland, 1938/1972; Curcio, 1987). First, comprehending and interpreting graphs requires the ability to use abstract and logical reasoning, spatial visualization, and concrete experience to formulate and integrate knowledge of graphs (Benbow & Minor, 1986; Brasell, 1987b; Maccoby, 1966; MacDonald-Ross, 1977; Price *et al.*, 1974; Wavering, 1983). In general males exhibit greater spatial skills and formal (logical) reasoning ability than females, although these differences are frequently not apparent until adolescence (Finn *et al.*, 1979; Graybill, 1975; Hernandez *et al.*, 1984; Levine & Ornstein, 1983; Maccoby & Jacklin, 1974; Rosenthal & Rubin 1982; Witkin *et al.*, 1977).

Second, gender differences are apparent in reading graphs, graph comprehension and science achievement, which might influence students' performance as they use the MBL's to learn graphing techniques. Results of the *National Assessment of Educational Progress* reveal that 13 and 17 year-old females have significantly fewer experiences in science than boys in every category from watching an egg hatching to visiting a mine or quarry (Kahle & Lakes, 1983). This lower exposure to a scientific environment might lead to less competence in science. The most recent international study, conducted in 1986, again found that boys scored higher than girls on large-scale science tests *at all levels* with the difference increasing from elementary school through high school (International Assessment for the Evaluation of Educational Achievement, 1988). Generally only small differences are noted for biology, but increasing differences are found for chemistry, earth/space science and physics achievement (Steinkamp & Maehr, 1983; Kahle, 1985). The greatest differential is seen for physics participation and achievement, and males are reported to continue to do better in the physical sciences as they grow older (Benbow & Minor, 1986; Erickson & Erickson, 1984; Tamir, 1987).

Although the gender difference in science achievement scores has been widely noted for at least fifteen years and a large body of research has been generated on the subject, the cause of, or explanation for, this difference remains a matter of speculation (Howe & Doody, 1989; McGee, 1977). Since gender differences are consistently found in measures of spatial and abstract thinking skills, it might be argued that gender differences will also be found in MBL's that make use of these skills. Yet, past research on MBL's suggests gender differences were not consistent across studies.

(2) Effects of students' level of ability

Research on the relationship between level of ability and achievement in MBL's is limited. Thus, in this section, I will discuss the relation between ability and achievement with, and without, a computer in order to frame a theoretical background for my research. Several studies have investigated the relationship between student variables (e.g., ability, motivation, etc.) and the effectiveness of computer-assisted instruction. Research has documented instances in which certain designs for instructional software have negatively influenced the learning of very high ability students (Cronbach & Snow, 1977; Snow & Lohman, 1984). One student variable greatly in need of further investigation is student's ability and its relation to achievement (Adams *et al.*, 1987). As McGowan and Clark (1985) point out, there is increasing evidence of an inverse relationship between student ability and instructional method. Standard students are often found to profit from instructional methods that mirror the behaviorist principles. Honor students, on the other hand, are often found to ignore behaviorist instructional methods in favor of their own idiosyncratic learning strategies or to profit more from "less" instruction (Bovy, 1981). This finding often results in evidence that the higher instructional support offered by the behavioral software benefits students at all ability levels. However, when general ability is taken into account in aptitude-treatment interaction (ATI) studies, many honor students learn much less from highly supportive methods such as the traditional classroom. Conversely, when instructional support is reduced, as it often is in "discovery" (or creative) teaching strategies, honor students shine and those with lower ability achieve less. There is a great deal of research evidence for this generalization (e.g. Cronbach & Snow, 1977; Salomon, 1979). It now forms one of the foundations of newer instructional theories (e.g. Snow & Lohman, 1984, cited in McGowan & Clark, 1985).

Another explanation of ATI claims that higher-ability students are already capable of thinking abstractly. Therefore, putting high-ability students in a high-support environment will not necessarily provide substantial improvement. Mayer (1979) has also speculated that higher-ability students already have learning strategies that interfere with the high-support treatment. Giving high support to this kind of student is like trying to force an unnecessary performance strategy on an accomplished musician.

Among current MBL studies, very few have examined the relationship between students' ability and their ultimate achievement. Results from a quasi-experimental study of MBL by Mokros and Levine (n.d.) reveal the teacher's approach to using MBL was most flexible with the honors students, and most structured with the special-needs students. In that case, all classes *except* the special-needs students made significant gains in mathematics skills and understanding of scientific concepts. The results also show that students who have the greatest flexibility to use software tools to conduct their own investigations are the students who benefit the most from MBL tools. Zuman and Weinberg (1989) found that even special-needs students can benefit greatly from the use of MBL's, both in cognitive and affective ways. Kirkpatrick (1987) suggests that the use of MBL's are an ideal learning environment for *all* students because MBL's are relatively nonverbal, provide one or two steps at a time, and give immediate feedback. So, one must consider whether computer programs will work equally well with all types of learners.

II. Methods

In this study, I investigate whether an innovative learning environment, the MBL, enhances students' learning in science, particularly in the study of kinematics. The research question that guides my study is:

Which situation (an MBL or a traditional laboratory environment) is more effective in improving students' achievement in interpreting kinematics, in constructing and in understanding graphs?

The sub-questions are:

(1) Do the outcomes differ by gender, and is there an interaction between gender and treatment?

(2) Do the outcomes differ by academic ability, and is there an interaction of student ability and treatment?

This study is a pre/post control group design in which subjects were stratified by level of ability and gender, and then randomly assigned to either the control or the experimental group.

1. Subjects

The subjects were seventh grade students (N = 71) in four classes; two honor and two standard classes. Their average age was 13. There were two reasons for choosing seventh graders as my subjects. First, the most complete data available from previous research was for students between seventh and twelfth grades; so I have been able to compare my findings with earlier research. Second, by selecting these particular classes, I ensured that subjects in the sample had a homogeneous social background.

Students were randomly assigned to each experimental group according to tables of random permutations (Cochran & Cox, 1957:577-583). The design turned out to be an unbalanced research because I had more honor students than standard students but with almost equal total numbers of girls and boys in each experimental group (See Table 1). One of the strengths of this study was that students were randomly assigned to each experimental group within the class, so there was no selection bias on subjects in each subgroup. Thus, despite the relatively small sample, this study is reliable enough to permit generalization.

All students had learned bar, pie, and some line graphs (i.e., with stock market trends) in a mathematics class earlier in the academic year. For this research, I assumed that (1) the students within each treatment had the equivalent exposure to the graphing curriculum, (2) the students were novices to kinematics concepts, and (3) the randomization compensated for unknown differences between the treatment groups. Only one student, who missed the pre-test, was eliminated from the analyses.

Table 1. Number of Students in Each Treatment Group

		Group			
		Treatment		Control	
Class	Total	Girls	Boys	Girls	Boys
Honor	45	13	10	13	9
Standard	26	5	8	4	9
Total	71	18	18	17	18

2. Treatment group

In the MBL treatment environment, a computer software package called "Motion Grapher" was used to carry out much of the "busy work". This program registers a student's distance from a sensor, collects experimental data, and graphs the student's motion on a two-dimensional graph of distance versus time, or velocity versus time, and so forth. The curriculum for the treatment group was adapted curricula supplied by Technical Education Research Centers (TERC), Cambridge, MA, U.S.A. and Thornton's research (1988).

Students worked in groups of at least two and no more than four. All of the students were encouraged to take turns using the computer to complete the activities and to work as a group in formulating their worksheet answers and graphs. The teacher acted as a resource, providing assistance upon students' request.

3. Control group

In this study, the traditional classroom was a setting that allowed students to work in groups on their activities without a computer. The classroom was remodeled as a laboratory with lines on the floor marked off in meters for students to perform their movements, and a stopwatch to measure the time for each movement.

The activities included taking measurements, performing calculations, and constructing tables and graphs to report experimental findings. Students used materials similar to the experimental group's, but they were required to construct a table and use equations to perform calculations before they drew the graphs. The activities were confirmed by the cooperating teacher. The control group was informed that they could use the MBL after the study was completed.

4. Procedure

A pilot study was conducted before running the experiment. The pilot had two phases, each with six students. The first phase was conducted to test written materials and software. Several changes on the worksheets were made to make them more readable and feasible. Then, the materials were reverified with the teacher after revision and re-administered to the second pilot group. Limited changes were made after the second investigation.

The research activities included (1) a pretest and a pre-questionnaire in a regular classroom setting, (2) three experimental activities, and (3) a posttest and the attitude questionnaire.

There were three major activities. Each one deals with distance, velocity and both distance and velocity graphs. The activities were designed to be as similar as possible for both groups with the exception of the use of MBL computers. Observations were taken on several occasions each day. Student interactions with the activity, and with one another, and teacher interactions with the students were observed. The observations obtained in both settings were used to document the two environments and to provide relevant background for understanding and distinguishing them. Thus, I can confirm that the appropriate curricula were being applied, and was able to validate the implementation of the treatments proposed.

In both groups, students worked in small groups to accomplish the experiments, but each student wrote his or her own individual report. Group size ranged from two to four. Two or three were recommended both by the developers of the MBL's and by other researchers (Johnson & Johnson, 1983). According to Johnson and other researchers (1988), good cooperative learning groups tend to range in size from two to six. The shorter the periods of time available, the smaller the learning group should be with two or three being the best. Therefore, I randomly assigned either two or three students to conditions, stratifying by gender and ability. Even though having four members in one group was controversial, one out of the 26 groups was scheduled to have four students because of a lack of space.

5. Measures

There are two pretests: first, Test of Graphing Skills (TOGS). Four items were selected from the original TOGS (KR-20) after consulting with the test designers (McKenzie, 1989) because they had the highest item-total correlation coefficients computed on the seventh grade sample (over 40%). Two items tested construction ability and the other two tested interpretative ability. Second, Content-Related Motion Test. A content-related (kinematics) pre-test was used as a second pre-test to measure students' prior knowledge of motion concepts. The instrument was adapted from Technical Education Research Centers' and Thornton's studies. Some of the test items were multiple choice and some of them were open-ended questions. They were validated using content and expert-opinion-validation procedures.

A questionnaire was administered in order to document students' background. Information obtained included gender, age, level of interest in math and science, and where students had used computers.

The post-test consisted of two parts: the four items from pre-test 1 and alternative pre-test 2. The alternative version of pre-test 2 was modified from pre-test 2 and several items were created by the researcher. The test items concentrated on the students' understanding of distance versus time and velocity versus time graphs in a variety of situations, as well as understanding how students interpreted their choices.

A questionnaire on students' attitudes towards the learning environment was completed by each student after the experiment. The questionnaire consisted of several Likert-type items which ranged from negative responses (i.e., very difficult) to positive responses (i.e., very easy). Data from the questionnaire were specifically used for supplementary interpretation and explanation of findings from the post-test.

III. Results and Discussion

A series of multiple regression analyses were conducted to search for variables important in predicting the dependent variables of interest. The regression models tested included both covariates and independent variables. The pre-test was included as a covariate in order to increase the power of the analyses.

Overall, total scores on the post-test are positively related to students' performance on the pre-test. This positive relationship also applies to the scores for the subtests on distance-time and velocity-time graphs. As displayed in the figures below, honor students outperformed standard students on the overall post-test as well as on the subtests for distance-time and velocity-time graphs, regardless of their scores on the pre-test.

Figure 1 displays scores on the post-test as a function of pre-test scores, ability level and treatment. The fitted lines have length representing the range of pre-tests scores in each group. The graph shows that, on the average, regardless of the scores on the pre-test: (1) honor students had higher scores than standard students, (2) honor students in the treatment group outperformed honor students in the control group, (3) standard students in the treatment group had higher scores than standard students in the control group, and (4) no interaction was detectable at .05 significance level ($R^2 = 62.71\%$, $p < .0001$).

Figure 2 displays scores on the distance-time subtest as a function of distance-time pre-test scores, ability level and treatment. Again, the fitted lines have length representing the range of distance-time subpre-test scores in each group. For students' achievement on the distance-time subtest, the same positive relationship between the post-test and the pre-test scores exists. Both treatment and level of ability factors were significant predictors of students' performance, and the same interpretations can be applied ($R^2 = 53.26\%$, $p < .0001$).

Students' performance on the velocity-time subtest was related to students' ability, gender, pre-test scores, and interaction between ability and gender. Treatment was not a significant predictor of performance on the velocity-time subtest. The interaction term of gender and ability is significant but not the main effect of gender. Once again, overall, honor students had higher scores than standard students on

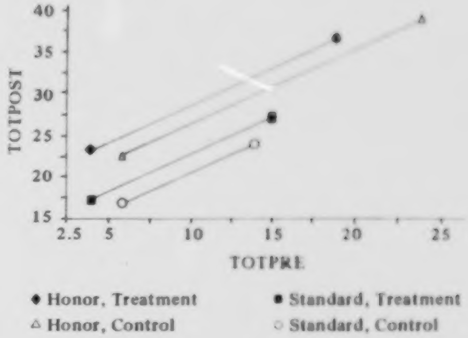


Fig. 1. Fitted regression models displaying the relationship between post-test (TOTPOST) and pre-test (TOTPRE) for honor and standard students in each experimental group

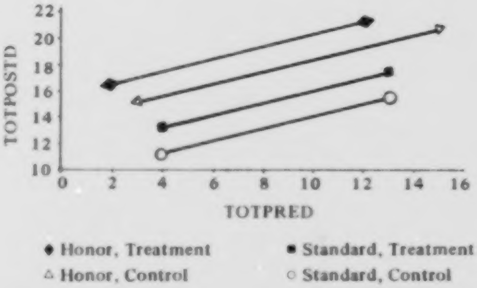


Fig. 2. Fitted regression models displaying the relationship between distance-time post-test (TOTPOSTD) and pre-test (TOTPRED) for honor and standard students in each experimental group

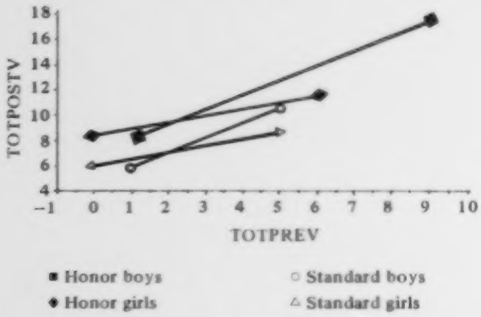


Fig. 3. Fitted regression models displaying the relationship between velocity-time post-test (TOTPOSTV) and pre-test (TOTPREV) for honor and standard students

the velocity-time subtest, regardless of their scores on the velocity-time pre-test ($R^2 = 57.61\%$, $p < .0001$, Figure 3). However, the slope of the TOTPOSTV vs. TOTPREV relationship was greater for boys than for girls in each class. In other words, on the average, boys improved their performance on the velocity subtest more than girls in each class.

One possible explanation for this finding was that the boys started at a higher level of understanding of the distance concept than the girls because they have had more personal experiences in the physical world. The higher level of understanding of distance prepared them to shift their knowledge to understanding velocity more easily. Thus, they appear to be able to understand the abstract concept more readily. A second possible explanation was that boys were more able to approach and to think abstractly than girls (Kahle & Lakes, 1983). Another possible explanation was that the difficulty of understanding velocity graphs might be not only because of those graphs' abstract features but also due to the complexity of information processed from a three-dimensional movement to a two-dimensional graphic representation. With a short response time during the experiment, female students (who are always considered as less capable in science) might lack the capacity to execute this complex process.

1. Gender effect

Gender was not a significant predictor of any of the post-test scores except for the velocity-time subtest, once pre-test scores were included in the models. This supports research indicating that there are no significant gender-related differences with respect to graph comprehension. However, it is inconsistent with findings from Brasell and Thornton in which females and males with the use of MBL's had significant differences in their performance. The reason for this inconsistency is that there were pre-existing differences between boys and girls on the pre-test and, once this latter score was included as a covariate, gender on the pre-test was no longer an important covariate. In other words, in terms of these types of skills, there are differences between boys and girls but these differences existed *before* they were exposed to MBL's.

If scores for the pre-test are taken away from the regression models, gender effect became a predictor for the total post-test and distance and velocity subtests. The results indicate that boys outperformed girls on the post-test after controlling for class and treatment effects ($R^2 = 46.05\%$, $p < .0001$). The same interpretation can be applied to students' performance on the distance subtest ($R^2 = 48.64$, $p < .0001$). Boys were also better than girls on the velocity subtest after controlling for class ($R^2 = 29.91$, $p < .0001$). However, treatment was not a significant predictor. There was still no interaction between gender and treatment.

2. Working group as the unit of analysis

Because students worked together in groups, I conducted a similar series of multiple regression analyses with data aggregated for students who worked together as a group during the experimental period. Findings from these analyses are consistent with the results for predicting the scores on the post-test using the individual as the unit of analysis.

3. Difficulties with scientific graphs

The questions on the tests are diverse and reveal inconsistencies in students' knowledge. From their responses to the test items, five categories of students' problems were identified.

(1) One group of difficulties concerns making the translation from verbal descriptions or situations to graphs. This task required students to differentiate appropriate graphs (positive or negative slope graphs, curve graphs) given particular situations. This activity dealt with construction ability.

(2) A second group of difficulties concerned the translation of graphic representation into written descriptions. Given graphs with a variety of slopes of line segments, students needed to locate the right line segments for the situations. This used students' ability to interpret graphs.

(3) Another technique for graphical translation is to convert one graph into another corresponding

graph. In this study, students were required to construct velocity graphs from distance graphs. This is somehow more complicated than the other categories because it not only requires students to understand the current graph but it also demands that students "decompose" each segment of the graph. By "decompose", I mean that students need to analyze a line graph as segments with different slopes.

(4) A fourth group of difficulties is the distraction that *a graph is a picture of a situation*. Overcoming this difficulty is partly dependent on the ability to understand the relationships between two variables represented on a cartesian graph (Brekke, 1987). Many students simply returned to their intuitive conceptions to explain events they had not studied in science. Examples of these conceptions are illustrated by the commonly held view that the graph of the path of a travelling object appears like its trajectory.

(5) The last group of difficulties had to do with providing a rational explanation for a chosen answer (e.g. explaining how one chose one's answer). In order to further confirm that the answer was not a guess, several items requested students to provide reasons for selecting a particular answer. My analyses suggest that students were unable to give "appropriate and clear" reasons for particular answers. The students tried to use their intuition and daily experience to solve problems. Limited scientific knowledge was applied to make the interpretation reasonable.

Table 2 is a summary table of the percentage of items answered correctly in each group on the post-test.

The table reveals several trends. First, within each group of problems, there was a fairly consistent treatment effect, with the percentage of correct items on the post-test being greater in the MBL group. The biggest difference between pre- and post-test was found in category II for both groups. As I would expect, students tended to capture the meaning of the graphs (concrete representations) well and were able to apply it to situations in which they were required to distinguish appropriate segments of the line in order to match the descriptions (abstract representations). So it is understandable that students should have less difficulty translating from graphs to words, than from words to graphs.

Second, an extremely low percentage of students' performance on the post-test was found in category III even though students made considerable improvement in both groups. There are two levels of difficulty in solving this problem: data must be read from graphs and then converted into the second graph. The second level of problem solving skill is much more complex and crucial and required more mental effort on manipulation of quantities on the graphs. Questions in this category were not like the other categories which used a multiple-choice format. This raises the question of whether students were benefiting from clues in the question format in other categories rather than understanding the concepts that were supposedly being tested. One surprising finding was that, even with hands-on experience of graph construction, students in the control group did not gain as much as treatment students between pre- and post-tests.

Very often, students simply duplicated a positive slope of distance-time graph (stands for an object with a constant velocity) to a velocity-time graph with a positive slope. The velocity-time graph became a graph indicating a movement with acceleration instead of constant velocity. However, almost no

Table 2. Percentages of Students' Correctly Responding in Each Category of Difficulties

	Group					
	Control			Treatment		
Category	Pre-test	Post-test	Diff	Pre-test	Post-test	Diff
I. (D--->G)	46.64	54.56	7.92	48.09	62.07	13.98
II. (G--->D)	47.51	67.19	19.68	46.69	66.75	20.06
III. (G--->G)	8.35	20.10	11.75	6.80	25.80	19.00
IV. (Picture)	43.34	48.76	5.42	43.22	52.40	9.18
V. (Reasoning)	20.60	33.49	12.89	22.06	38.86	16.80

D: Descriptions
G: Graphic representations
Picture: Graph as picture of a situation
Reasoning: Explanatory (or reasoning) ability

single student was able to identify a new scientific quantity (acceleration) just created on a velocity-time graph through their misconception of a graph.

Third, limited increases between pre- and post-test in category IV were apparent for both groups. This indicates that about 50% of the students were still having difficulty in remedying their misconceptions of the graph-as-picture. Other supplementary learning strategies are obviously required to enhance students' understanding. Finally, as expected, more students tended to answer open-ended questions correctly after treatment. They can distinguish the right answer from the distraction even though they cannot explain why they thought so. However, in inspection of their responses, the scientific language used was strikingly sophisticated.

4. Examples from the test

In this section, I will provide examples from the post-test to illustrate students' errors along with some typical answers. I have selected items that had the lowest percentages correct within each category. Due to the similarity of response from both treatment and control groups, I will present examples from both groups to reflect their common mistakes.

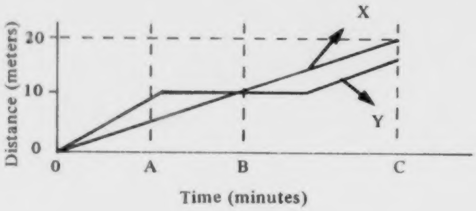
Category I (D--->G) In this category, the most trouble students had involved the translation of velocity graphs. This difficulty was not eliminated even after treatment. For instance, overall, 60.6% of the students chose a positive slope velocity graph for an object moving away from the origin with a constant velocity and 52.1% of students chose a negative slope velocity graph for an object moving toward the origin with a constant speed. Also, 32.4% of the students selected a velocity graph with a horizontal line indicating positive constant velocity for an object standing still, instead of a graph with a horizontal line representing zero velocity. They also paid little attention to sign (positive or negative) in velocity graphs. This confusion between height and slope for distance and velocity graphs and between directions of the physical movements, indicates that students had difficulty thinking abstractly, critically, and systematically about velocity graphs. They simply retrieved images of distance graphs without critical evaluation of the data shown on the graph or without making use of their scientific knowledge. This effect can also be seen on the worksheets, when they were required to predict graphs that represented movement.

Category II (G--->D) Even though students improved the most in this category, they still showed difficulty in comparing (or relating) pairs of movements on both distance and velocity graphs. Overall, the majority of students (76.1%) were unable to distinguish two objects moving at the same speed from a distance graph. For instance, a tortoise and a hare have a race (See Figure 4). They both start at the same place and finish 20 meters away. Instead of choosing C for a question on two objects with the same speed, they chose the intersection of the lines (B, meeting at same place) for the answer. The low percentage correct in this category (G--->D) might be due to the complicated situation presented in the graph in which there were several different slopes for comparison. This further confirms that students lacked skills to apply what they had learned from this experiment to information presented in graphs and then to analyze information critically.

Category III (G--->G) The lowest percentage correct was found for items in category III (20.10% for the control group and 25.80% for the treatment group), even though students made considerable improvement in this category (11.75% for the control group and 19.00% for the treatment group). Commonly, students saw the graph as a whole rather than considering the line to be constructed from many points. Very few students were able to "de-compose" the lines in each sector in order to obtain the magnitude of velocity for each movement. Typical answers simply duplicated the distance graph as the velocity graph without further transformation. This appears consistently through all the test items. One possible

A tortoise and a hare have a race. They both start at the same place. The finish line is 20 meters away. They move as follows:

Tortoise: Walks at a slow, steady (constant) velocity for C minutes.
Hare: Walks at a fast, steady velocity for A minutes, rests for a certain minutes, then walks at the same fast velocity to the end of minutes.



The tortoise wins the race by a nose.

Choose either X or Y for the following two questions.
——— 29. Which line graph is for tortoise's movement? (X or Y)
——— 30. Which line graph is for hare's movement? (X or Y)

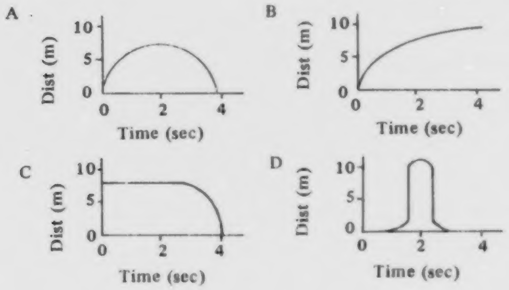
Fig. 4. A sample item for Category II

explanation was that students were not given explicit instructions about decomposing each segment of the distance graphs in order to construct velocity graphs. Thus, they simply recalled their "templates" of distance-time graphs as velocity-time graphs.

Category IV (Graph-as-Picture) It seems that students had difficulty in remedying their misconceptions of the graph-as-picture, especially, when the test items dealt with an object moving *vertically* (up or down, see Figure 5a) instead of *horizontally* (forwards or backwards, see Figure 5b). It seems that a two-dimensional representation (the graph) did not directly help students to understand how a three-dimensional activity could be logically drawn on the screen. I believe that there are two reasons why students failed to solve problems that involved these novel situations. First, students' experience with motion in the experiments emphasized movement toward or away from the origin (The "origin" means the 0 meter mark on the floor for the control group or the computer monitor for the treatment group). Second, perhaps not enough time was spent in class discussions and students were not given enough time to assimilate their laboratory observations and to understand the scope of the principles being illustrated.

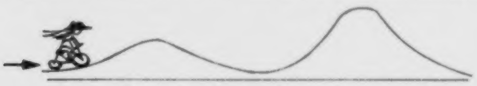
26. A student throws a ball straight up in the air, watches it come back down and catches it.

____ 26A. Which graph below shows the distance traveled by the ball?



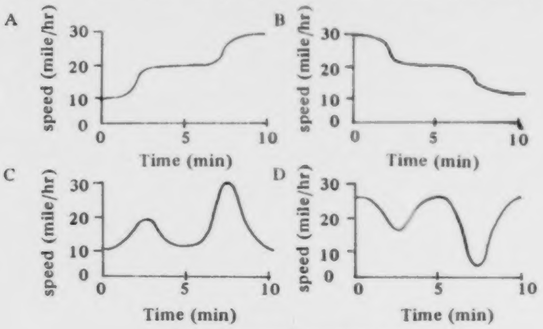
5a

27. A bicyclist is riding over some hills as shown in the picture below:



She slows down going uphill and speeds up going downhill.

________ Which of the graphs below best shows the bicyclist's speed?



Explain how you chose your answer

5b

Fig. 5. Two sample items for Category IV

For instance, a comparison of the results on items 5a and 5b on the post-test shows students' difficulties. Item 5A asked students to choose a graph representing the distance of a ball thrown straight up in the air. Item 56 asked students to choose a graph representing the velocity of a bicyclist riding up and down hills. For item 5a, 24.3% of the students answered the item correctly on the pretest and 32.4% answered correctly on the post-test. In contrast, 56.3% were able to answer item 5b correctly on the pre-test and 70.4% answered correctly on the post-test. Most incorrect responses to item 5a involved a highly visual representation of the ball's rise vertically into the air. This suggests that fewer students made the mistake of recognizing a graph as a picture when the situation was similar to their experimental experience. However, this did not hold true when the object's movement was vertical. In terms of cognitive burden, this suggests that the task of thinking abstractly and in a less familiar dimension has an extra mental cost.

Category V (Reasoning ability) Even though students were able to identify erroneous graphs, few of them were able to explain why the graphs were wrong. Several typical incorrect answers are shown below.

The correct answer for post-test item 5a (See Figure 5) was A, but the common answer was D (60.6% of the students chose D for this item.). A sample of explanatory responses as listed below:

> *I chose (D) because it looks straight, and it goes up and comes right down, just like a ball does.*
>
> *I chose (D) because the ball gains distance by going up, then it comes down, and the distance decreases.* [This student even made a comment that we did not learn this and I don't really understand it.]

Similar findings of incorrect answers are shown in the post-test item (See Figure 6) whose preferred

26B. Which graph below shows the velocity of the ball (its speed away from the student)?

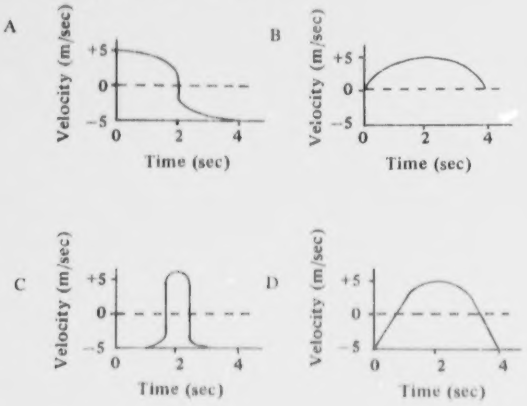


Fig. 6. A sample item for Category V

answer was (B) (40.0% of the students chose B for this item).

> *I choosed* [chose] *this graph because it starts at zero and ends at zero and shows the velocity in between.*
>
> It [Its] *speed gets higher because of the force and then slows down because of gravity.*
>
> *I chose answer B because it showed that the ball went up and down at the same speed and it is an even movement.*

As we can see, students paid little attention to the sign of a velocity-time graph with different directions of movements, a picture (or image) of an object's movement dominated their understanding and interpretation considerably.

For students who were able to deal with velocity graphs, typical correct answers were:

> *because this* [is] *the only graph that starts with the ball going away (+) and ends with it coming toward (−) the boy.*
>
> *up is + (pos), down is − (neg)*

From these responses, we see that students gave answers that ONLY made sense to themselves. Their spontaneous interpretations were mainly derived from their intuition of the graphs, daily experiences with the physical world, or clues from the story lines in the problems. Seldom did they generate any logical interpretations or scientifically sound phrases for the situations presented. Few students made use of the scales or units of the axes to determine the relationship between the variables. With little attention paid to the units and personal intuition of experiences dominating their comprehension, students still lack the ability to apply their knowledge to similar but more complex situations. Their understanding seemed limited to distance graphs.

5. *Attitudes toward the experimental activities*

A post-treatment questionnaire with 18 items about students' attitudes toward the experimental activities was administered to all the students in both groups after completing the research. There were several findings. First, on the average, students in both groups reported that the activities on distance-time graphs were not difficult to learn and complete. However, they rated difficulty as increased when activities included the concept of velocity and transformations between velocity-time and distance-time graphs. Second, more MBL students rated all the motion activities interesting than students in the control group. Third, most students felt the distance-time and velocity-time activities clear but they rated the transformation between distance-time and velocity-time activities as more confusing. Finally, a majority of the students gave positive responses to their partners' support and provision of useful opinions for comprehending the materials and tasks. However, there was a difference between honor students and standard students in their responses to frustration arisen from the activities. Honor students felt less frustrated than did standard students using the MBL as a learning tool. I attribute this finding to the fact that honor students knew more and and were more capable of solving problems and confronting difficulties by them-selves. In contrast, ordinary students tended to feel more frustrated by using the MBL tool for learning because they needed to explore their findings from the activities.

IV. Conclusion

The findings of this research reveal that important predictors of students' performance on the post-test were the levels of students' ability and the treatment. That is, controlling for scores on the pretest and class level, students in the MBL group had significantly higher scores than did the students in the control group, on the average. Also, controlling for treatment effect and pre-test scores, students in the honor classes scored higher. In addition, the treatment had the same effect regardless of student ability. The main contribution to the difference between treatment and control group was due to differences on the subtest of distance items. There were no differences between the treatment groups on the subtest of velocity items.

From responses to the test items, five categories of students' problems were detected. Students had difficulty (1) translating from verbal descriptions or situations to graphs, (2) making the reverse translation from graphs to written descriptions, (3) constructing velocity-time graphs from distance-time graphs, (4) not viewing the graph as a picture of the situation, and (5) giving rational explanations for chosen answers. Students improved the most on items that required them to translate from graphs to written descriptions. This suggests that experiences in this study helped students to be better graph interpreters. However, they were still incapable of constructing velocity graphs from distance graphs. This was evident both on their post-test performance and on their worksheets.

In order to maximize my understanding of the activities involved, and the complexities of the interactions encountered, observations were taken on several occasions to "triangulate" my findings (Miles & Huberman, 1984; Webb *et al.*, 1965; Merriam, 1988). Peer collaboration was found more frequently between and within groups in the computer setting in which students were more likely to develop their communicative skills and verbal interactions. Through discussion, they also had more opportunities to link their experimental activities to the results. In contrast, students in the control group were more quiet and there was less intergroup mingling.

In addition, the findings show that the speed at which data could be collected with computers was an important factor. In general, students in the computer group could do the entire curriculum several times, while students in the control group did not have enough time. Thus, when students in the computer group made a mistake, they had time and were willing to do the experiment again. However, this feature and the easy accessibility of the MBL did not help students' understanding of velocity graphs very much because few students were able to make reasonable predictions on velocity-time graphs after practicing the activities several times. This might explain part of the reason for limited improvement of students' performance on velocity test items. Explicit instructions are needed with high technology in order to enhance students' learning of complex scientific concepts.

V. Limitations and Implications

1. Limitations

A number of limitations exist in this study. First, the results are only generalizable to middle-class seventh-grade students. Second, the results are limited to individual performance on content-specific (kinematics) tests; the test items were iconic representations, verbal descriptions or open-ended questions rather than questions asking students to perform calculations. Finally, the results of this research are limited to line graphs for motion representations; they cannot be generalized to other graphic representations across the curriculum. This is, however, one of the first true experimental studies comparing the effectiveness of MBL's and traditional laboratories.

2. Implications of this study

This study has implications in three areas: (1) teaching for understanding, (2) introducing technologies into schools for making a distinct contribution to science education, and (3) linking daily experiences to school practice.

3. Teaching for understanding

Results from this study reveal that students gained more scientific knowledge and graphing skills with the MBL technology during a short time. Conceptual difficulties were eliminated or reduced and motivation for learning scientific phenomena was increased. However, within this short period, there was not sufficient time to develop a truly robust integrated understanding. Students need to receive both *explicit instructions* and *powerful tools* from the learning environment that will enable them to see relationships between experimental data and graphic representations. Much of the earlier thinking saw the computer as replacing at least some of the functions of the teacher. The new vision sees the technology as supporting excellence in teaching; it seeks enhancement — not replacement — of the teacher (Papert & Tinker, 1988). Therefore, teachers' instructions should be appropriately integrated into classroom learning; profound knowledge about students' difficulties and an understanding of the advantages and disadvantages of technology by the teachers are also important issues to be considered. As Krajcik and Layman point out (1993), MBL is only a tool, and unless teachers have well-integrated understandings of the science concepts and the presses associated with the experiments, students will not benefit from the use of these tools. Therefore, in order to use the tool effectively, teachers should design their own activities for integrating the MBL's into curriculum and providing sufficient guidance to work with the new learning tool. Also, the teacher should encourage peer collaboration and promote more discussions among students while using the MBL's. In this way, students might be able to develop their own planning hypotheses, processing negotiation, and explanations skills in learning sciences.

It is common for students simply to use their intuition to face scientific phenomena uncritically, as we can see from my analyses of misunderstanding of graphs and the velocity concept. For instance, it is hard to understand velocity versus time graphs because an object's velocity, unlike its distance, is not directly observable. Even though my students gained on the distance-time graphs, with such a short period of experiment and limited support from the teacher, the students' achievement was not significantly improved on the velocity-time graphs. This might suggest that graphing skills should be introduced in earlier grades and be properly emphasized in both the science and math curriculum. Also, the work of Linn and her colleagues (Linn *et al.*, 1991; Linn & Songer, 1988) and Thorton and Sokoloff (1990) indicates that making predictions prior to performing an MBL activity appears to enhance students' concept learning. Then, later, students may be able to make a better linkage between graphs and experimental data, to analyze and to interpret the information presented in a two dimensional representation, and to predict the outcome of experiemental data. So,

> teaching for understanding must foster knowledge of the phenomena being studied, of the key concepts useful in analyzing these phenomena, of the current scientific explanations of them, and the relationships among data, concepts, and explanatory schemes within the relevant subject areas (ETC, 1988).

4. *Introducing technologies into schools for making a distinct contribution to science education*

In general, formal concepts of kinematics in science are introduced in high schools when students have better basic discipline and preparation in science. Thelen (1976) has indicated the importance of students' readiness for a particular subject content. In her monograph, she emphasizes the need to link new knowledge to students' existing cognitive structure:

> If a student is forced before he masters the necessary backlog of experience for the concept of energy, he may become frustrated and resort to memorization of definitions and trivia. Student preparation is an important and a neglected area of teaching. (cited in Stallings, 1982).

My study has revealed that even seventh grade students, who have just entered junior high schools for formal training in science, made significant improvements in learning kinematics (which is usually taught in high schools). New technology, such as MBL's, should be adopted not for their own sake, but rather when they offer clear advantages over traditional educational materials and when they make it possible to introduce scientific concepts into the curriculum earlier and more effectively.

The fact that MBL's influence students' performance equally at all ability levels opens an avenue for a variety of students to make use of MBL's. MBL's increase learning efficiency. Students have an opportunity to understand and use particular representations (for instance, a single distance-time graph or a split screen for both distance-time and velocity-time in Motion Grapher software) for a better match between themselves and the subject matter.

In addition, the lack of a gender effect in my analysis is also heartening. As research reveals, thirteen is a pivotal age in the development of strong likes and dislikes for different subject areas in young people (Rogers, 1984). In the United States, girls are the equal of boys in mathematics and science until sixth grade, but thereafter girls often develop a negative attitude toward these subjects and avoid them in high school, thus limiting their career opportunities. This research informs us that the use of technology does not discriminate between genders.

5. *Linking daily experiences to school practice*

The result shows that it was helpful for students to collaborate with others to productively complete the task. Peer interaction encourages cooperative solution of problems and communication produces the need for checking and confirming thoughts. If teachers wish to maximize achievement and foster positive verbal interaction and problem-solving among students, then instructional support, such as MBL learning tools, may help students use their time more effectively, be more motivated, more efficient and may provide more dynamic learning environments for stimulating heuristic thinking.

While we need to know much more about how

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attitudes influence learning, it appears that nationwide, many students never study much science until the seventh or eighth grade. At that time they are placed in courses where they are abruptly confronted with a strange new vocabulary, difficult reading material, and some kind of laboratory experience. If their first or second science course does not provide them with a positive experience, they quickly lose interest and end up disliking science (Conant, 1974; Simpson, 1978). Therefore, with the promising advantages of MBL's, school policy makers should support the infusion of educational innovations into current practice in order to augment laboratory functions.

Given the fact that providing opportunities for students to link their daily experience with multiple representations through the use of the MBL innovation, students no longer will *memorize* to *forget*. Their ***hands-on*** experience will help them *remember* and ***understand***.

Therefore, guiding students to relate science curriculum to their daily experiences is an essential and vital issue in our current science education. Teachers can make good use of technology to supplement teaching strategy and to enhance learning, which they have long been struggling for. As Dieuzeide of UNESCO suggests:

> Instead of continuing to let the machine do what the teacher cannot do, we should ask ourselves what it is that the teacher should do that the machine cannot do. (cited from Olson, 1973)

With support from researchers and teachers in designing appropriate instructional tools, therefore, difficult science topics and experiments may become more inspiring and more interactive to most students in school.

The following Chinese proverb sums up a pedagogical philosophy for teachers and software developers to keep in mind when they work with young learners:

I HEAR, I FORGET.
I READ, I UNDERSTAND.
I DO, I REMEMBER.

References

Adams, D., & Schrum, J. (1988). *The effects of MBL exercises on the acquisition of line graph construction and interpretation skills by high school biology students.* Paper presented at the 61st annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, Missouri.

Adams, T.M. II, Waldrop, P.B., Justen, J.E. III, & McCrosky, C.H. (1987). Aptitude-treatment interaction in computer-assisted instruction. *Educational Technology, 27*(12), 21-23.

Anderson, J.R. (1990). *Cognitive psychology and its implications.* New York: W.H. Freeman and Company.

Bamberger, Sister C.F. (1942). *Interpretation of graphs at the elementary school level.* Catholic University of America Education Research Monographs, 13, Washington, D.C.: Catholic Education Press.

Barclay, W.L. III (1986). Graphing misconceptions and possible remedies using Microcomputer-Based Labs. *Proceedings of the National Educational Computer Conference* (NECC).

Benbow, C.P. & Minor, L.L. (1986). Mathematically talented males and females and achievement in the high school sciences. *American Educational Research Journal, 23*(3), 425-436.

Bestgen, B. (1980). Making and interpreting graphs and tables: Results and implications from national assessment. *Arithmetic Teacher, 28*(8), 26-29.

Bovy, R.C. (1981). Successful instructional methods: A cognitive information processing approach. *Educational Communication and Technology Journal, 29*(4), 203-217.

Brasell, H. (1987a). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching, 24*(4), 385-395.

Brasell, H. (1987b). *Sex differences related to graphing skills in Microcomputer-Based Labs.* Paper presented at the 60th annual meeting of the National Association of Research in Science Teaching, Washington, DC.

Brekke, G. (1987). *Graphical interpretation: A study of pupils' understanding and some teaching comparisons.* Shell Centre for Mathematical Education, University of Nottingham.

Brown, A.L., Bransford, J.D., Ferrara, R.A., & Campionone, J.C. (1983). Learning, remembering, and understanding. In J.H. Flavell & E.M. Markaman (Eds.), *Handbook of child psychology: Cognitive development* (4th ed.), Vol. 3. New York: Wiley & Sons.

Chiu, M.H. (1990). *The effectiveness of Microcomputer-Based Laboratories in teaching scientific skills and concepts: A comparative study.* Unpublished doctoral dissertation, Harvard University, MA.

Clement, J. (1985). *Misconceptions in graphing.* Paper presented at the Ninth Conference of the International Group for the Psychology of Mathematics Education, Noordwijkerhout, The Netherlands.

Clement, J., Mokros, J.R., & Schultz, K. (1986). *Adolescents' graphing skills: A descriptive analysis.* Paper presented at the annual meeting of the American Educational Research Association.

Conant, E.H. (1974). What do teachers do all day? *Saturday Review World, 1*(55).

Curcio, F.R. (1987). Comprehension of mathematical relationships expressed in graphs, *Journal for Research in Mathematics Education, 18*(5), 382-393.

Educational Technology Center (1988). *Making sense of the future: Teaching for understanding using computers in school.* Cambridge, MA: Harvard University, Graduate School of Education.

Erickson, G.L., & Erickson, L.J. (1984). Females and science achievement: Evidence, explanations and implications. *Science Education, 68*(2), 63-89.

Finn, J., Dulberg, L., & Reis, J. (1979). Sex differences in educational attainment: A cross-national perspective. *Harvard Educational Review, 49*, 477-503.

Graybill, L. (1975). Sex differences in problem solving ability. *Journal of Research in Science Teaching, 12*(4), 341-346.

Halloun, I.A., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics, 53*, 1056.

Hawkins, J., & Pea, R.D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24*(4), 291-307.

Hernandez, L., Marek, E., & Renner, J. (1984). Relationships among gender, age, and intellectual development. *Journal of Research in Science Teaching, 21*(4), 365-375.

Hoffmann, R. (1986). Piaget and microcomputer learning environments. *Journal of Learning Disabilities, 19*(3), 181-184.

Hofstein, A., & Lunetta, V.N. (1982). The Role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research, 52*(2), 201-217.

Howe, A.C., & Doody, W. (1989). Spatial visualization and sex-related differences in science achievement. *Science Education, 73*(6), 703-709.

International Association for the Evaluation of Educational Achievement (1988). *Science Achievement in Seventeen Countries*, Champaign, IL: Stipes Publishing Company.

Johnson, D.W., & Johnson, R. (1983). The socialization and achievement crisis: Are cooperative learning experiences the solution? In L. Bickman (Ed.), *Applied social psychology annual*, 4, 119-164. Beverly Hills, CA: Sage.

Kahle, J., & Lakes, M. (1983). The myth of equality in science classrooms. *Journal of Research in Science Teaching, 20*(2), 131-140.

Kim, H. (1989). *Microcomputer-Based Laboratories and learning: An ethnographic study of a science classroom in an urban elementary/middle school.* Unpublished doctoral dissertation, Harvard University, MA.

Kirkpatrick, D. (1987). Technology in education: A middle school teacher's experience. *Technology and Learning*, Volume 1, Issue 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Krajcik, J.S., & Layman, J.W. (1993). Microcomputer-based laboratories in the science classroom, *NARST News, 35*(1), 3-6.

Levine, D.U., & Ornstein, A.C. (1983). Sex differences in ability and achievement. *Journal of Research and Development in Education, 16*(2), 66-72.

Linn, M.C., Layman, J., & Nachmias, R. (1987). Cognitive consequences of Microcomputer-Based Laboratories: graphing skills development. *Contemporary Educational Psychology, 12*, 244-253.

Linn, M.C., & Lewis, E.L. (1989). *Heat energy and temperature concepts of adolescents, naive adults, and experts: Implications for curricular improvements.* Paper presented at the annual meeting of National Association for Research in Science Teaching, San Francisco, CA.

Linn, M.C., & Songer, N.B. (1988). *Cognitive research and instruction: Incorporating technology into science curriculum.* Paper presented at the American Educational Research Association Meeting, New Orleans, LA.

Linn, M.C., Songer, N.B., Lewis, E.L., & Stern, J. (1991). Using technology to teach thermodynamics: Achieving integrated understanding. In D.L. Ferguson (Ed.), *Advanced technologies in the teaching of mathematics and science.* Berlin: Springer-Verlag.

Lindquist, M.M., Carpenter, T.P., Silver, E.A., & Matthews, W. (1983). The third national mathematics assessment: Results and implications for elementary and middle school. *Arithmetic Teacher, 31*(4), 14-19.

Maccoby, E.E. (1966). Sex differences in intellectual functioning. In E.E. Maccoby (Ed.), *The development of sex differences*, 25-55. Stanford, CA: Stanford University Press.

Maccoby, E.E., & Jacklin, C.N. (1974). Myth, reality and shades of gray-what we know and do not know about sex-differences. *Psychology Today, 8*(7), 109.

MacDonald-Ross, M. (1977). How numbers are shown: A review of research of quantitative data in texts. *AV Communication Review, 25*, 4.

McCune, G.H., & Pearson, N. (1963). Interpreting material presented in graphic form. In *Skill development in social studies.* Thrity-third yearbook, National Council for the Social Studies, 202-209.

McDermott, L.C. (1982). Problems in understanding physics (Kinematics) among beginning college students with implications for high school courses. In M.B. Rowe (Ed.), *Education in the 80's: Science*, 106-128. Washington, D.C.: National Education Association.

McDermott, L., Rosenquist, M., Popp, B., & van Zee, E. (1983). *Student difficulties in connecting graphs, concepts and physical phenomena.* Paper presented at the American Educational Research Association Meetings, Montreal, Canada.

McGowen, J., & Clark, R.E. (1985). Instructional software features that support learning for students with widely different ability level. *Performance and Instruction, 24*(4), 14-17.

McKenzie, D.L., & Padilla, M.J. (1986). The construction and validation of the test of graphing science (TOGS). *Journal of Research in Science Teaching, 23*(7), 571-579.

Merriam, S.B. (1988). *Case study research in education: A qualitative approach.* San Francisco, CA: Jossey-Bass Publishers.

Miles, M.B., & Huberman, A.M. (1984). Focusing and bounding the collection of data, from *Qualitative data analysis: A sourcebook of new methods*. Beverly Hills: Sage.

Minstrell, J. (1982). Conceptual development research in the natural setting of a secondary school classroom. In M.B. Rowe (Ed.), *Education in the 80's: Science*, 129-143. Washington, DC: National Education Association.

Mokros, J. (1985). *The impact of microcomputer-based science labs* (Technical Report No. 85-2). Cambridge, MA: Technical Education Research Centers, Inc.

Mokros, J., & Levine, D.L. (n.d.). *The use and impact of MBL as a function of learner characteristics*. Cambridge, Massachusatts: Technical Education Research Centers, Inc.

Mokros, J., & Tinker, R. (1987). The impact of Microcomputer-Based Labs on children's ability to interpret graphs. *Journal of Research in Science Teaching*, *24*(4), 369-383.

Nachmias, R., & Linn, M. (1987). Evaluations of science laboratory data: The role of computer-presented information. *Journal of Research in Science Teaching*, *24*(5), 491-506.

Olson, D. (1973). What is worth knowing and what can be taught. *School Review*, *82*, 27-43.

Papert, S., & Tinker, R.F. (1988). *The MIT center for educational technology*. A proposal to the Department of Education, U.S.A.

Perkins, D.N. (1986). *Knowledge as Design*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Peterson, L.V., & Schramm, W. (1954). How accurately are different kinds of graphs read? *Audio-Visual Communication Review*, *2*, 178-189.

Price, J.R., Martuza, V.R., & Crouse, J.H. (1974). Construct validity of test items measuring acquisition of information from line graphs. *Journal of Educational Psychology*, *66*(1), 152-156.

Reynolds, R.E., & Baker, D.R. (1987). The utility of graphical representations in text: Some theoretical and empirical issues, *Journal of Research in Science Teaching*, *24*(2), 161-173.

Rosenthal, R., & D.B. Rubin. (1982). Further meta-analytic procedures for assessing cognitive gender differences. *Journal of Educational Psychology*, *74*, 708-712.

Salomon, G. (1979). *Interaction of media, cognition and learning*. San Francisco, CA: Jossey-Bass.

Shaw, E., Paddila, M., & McKenzie, D. (1983). *An examination of the graphing abilities of students in grades seven through twelve*. Paper presented at the annual meeting of the National Associational Association for Research in Science Teaching, Dellas, Texas.

Simpson, R.D. (1978). Relating student feelings to achievement in science, in M.B. Rowe (Ed.), *What research says to the science teacher*, Vol. 1. Washington D.C.: National Science Teachers Association.

Snow, R.E., & Lohman, D.F. (1984). Toward a theory of cognitive aptitude for learning from instruction. *Journal of Educational Psychology*, *76*(3), 347-377.

Stein, J.S. (1988). *How students negotiate understanding: Characterizing the problem-solving processes of dyads during microcomputer-based science labs*. Unpublished doctoral dissertation, U.C. Berkeley, CA.

Steinkamp, M.W., & Maehr, M.L. (1983). Affect, ability, and science achievement: A quantitative synthesis or correlational research. *Review of Educational Research*, *53*, 369-396.

Strickland, R.G. (1972). *A study of the possibilities of graphs as a means of instruction in the first four grades of the elementary school*, New York: AMS Press. (Original work published 1938).

Tamir, P. (1987). Some factors which affect science achievement of high school seniors in Israel. *Research in Science and Technological Education*, *5*(1), 69-92.

Thornton, R.K. (1986). *Tools for scientific thinking: Microcomputer-Based Laboratories for physics teaching*. A plenary lecture given at The International Conference on Physics Education, Nanjing, PRC, Sep.

Thornton, R. (1987). Tools for scientific thinking: MBL for physics teaching. *Physics Education*, *22*, 230-238.

Wavering, M.J. (1983). *More graphing and logical reasoning*. Paper presented at the meeting of the National Science Teachers Association, Dallas, Texas.

Weintraub, S. (1967). What research says to the reading teacher. *Reading Teacher*, *20*, 345-349.

Well, G., & Berger, C. (1985-6). Teacher/Student-developed spreadsheet simulations: A population growth example. *Journal of Computers in Mathematics and Science Teaching*, *2*, 34-40.

Wiser, M., & Kipman, D. (1988). *The differentiation of heat and temperature: An evaluation of the effect of microcomputer models on students' misconceptions*. Paper presented at annual meeting of the American Educational Research Association, New Orleans, LA.

Witkin, H., Moore, C., Goodenough, D., & Cox, P. (1977). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, *47*(1), 1-64.

Zuman, J., & Weinberg, A. (1988). Special needs students have fun learning about response time with MBL. *Hands on!* Cambridge, MA: Technical Education Research Centers.

Microcomputers in Graphical Representations

以微電腦為學習圖型表徵的實驗工具

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摘 要

本研究目的是在探討學生如何利用微電腦(MBL)爲實驗工具來學習二度空間中距離對時間和速度對時間的圖型表徵。本研究問題有三：(1)MBL 或傳統學習環境較能幫助學生瞭解圖型表徵？(2)性別差異的影響爲何？(3)學生本身能力的影響又如何？本研究同時也觀察師生在課堂上互動的情形，但不在本文討論範圍內。

研究結果顯示，學生能力高低和是否使用電腦對學生後測成績會有正面的影響。然而性別並非決定學習成就的因素。一般而言，實驗組較控制組表現要佳，但歸功於在距離對時間作圖的題目表現上，對於難度較高且較爲抽象的速度圖，則兩組不見其差異性。大部分學生在圖型技能上進步較多的是從圖型去解釋變數間的關係。而學生表現最差的則是由速度圖去建構出距離的相關圖。

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A Comparative Study of Taiwanese and Scottish Students' Problem Solving Skills as Performed in the International Assessment of Educational Progress 1991

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ABSTRACT

IAEP (International Assessment of Educational Progress) data were used to examine the nature and practices of Taiwan's science teaching, which has long suffered from teaching for examinations. The study was focused on problem solving skills shown in the IAEP performance test. In addition to the quantitative data from the IAEP, qualitative data were also collected through follow-up studies. Both structured and unstructured interviews were conducted to investigate the problem-solving strategies used by the participating students. Data were also compared to those in the similar study done by Dr. Brian Semple (1992) in Scotland. Results indicated that Taiwanse students attempted to rely heavily on taught methods whereas Scottish students could develop their own methods to solve problems.

Key words: problem solving, performance test, structured and unstructured interview, taught method and child method

I. Introduction

Competition is fierce on the small, overpopulated island of Taiwan; admission to schools above the ninth grade is based solely on entrance examination. Of the three-quarters of junior-high-school graduates who want more education, only about thirty per cent score well enough to go on to high school; there is a similarly low passing rate on the college entrance examination. As a consequence, education has become less important than preparation for examinations, and both teaching and learning have suffered. Although the number of both high schools and universities has increased considerably during the last few decades, the entrance examinations are still a central and unchangeable event in our society and also have become a heated issue in our educational community.

Since the world's science curriculum reformation movement in the 1960's, Taiwan has introduced the notions of student-centered learning and hands-on science in an attempt to improve the quality of our science education on both the elementary and secondary levels. Science and mathematics curricula have been carefully re-examined and improved to lead our science education toward the goal of "preparing our students to be citizens equipped with scientific literacy." However, under the great pressure of the entrance examination, teachers have been forced to teach for the test. As shown in research done by Wang *et al.* (1985), Taiwanese students usually go to extra outside classes after school for two to six more lessons of mathematics per week. At those classes mathematics and science are taught in a very different way. Great emphasis is put on the key points of each topic or chapter, analysis of test items, predicting the trends in entrance test items, how to memorize rules and apply them to solving test items.

In 1986, the National Science Council, R.O.C. decided to improve this situation by conducting a large scale study program named "Investigation Program on Secondary-School Mathematics and Science Instruction" under the co-sponsorship of the Ministry of Education and NSC. Many Science educators from science colleges of universities, educational testing experts and science and mathematics teachers were invited to the program which was planned to work under the notion of "improving the quality of test-items in classrooms and on the entrance examination to facilitate the normalization of instruction in science classrooms." After several years of effort some considerable numbers of of so-called "high order thinking skill test-items" were constructed and used in classrooms, and also appeared on the entrance examinations. However, most of our students were still taught how to solve "high-order" test-items (Yang, 1988).

In 1990, Taiwan, R.O.C. was invited to participate in the Second International Assessment of Educational Progress conducted by the Educational Testing Service, U.S.A. In the survey of 175,000 students worldwide which U.S. Secretary of Education Lamar Alexander called "the best international comparison of student abilites in 25 years (February 6, 1992, *The Washington Post*), 20 participating countries shared a common interest in identifying what is possible for today's 9- and 13-year-old children to know and do in mathematics and science. The survey also challenged some notions about what leads to academic success, e.g. class size, time spent watching TV, length of the school day, leisure reading at home, computers and other facilities and equipment in the classroom, science laboratory, per-cent of GNP spent on education, quality of teachers, and so on.

On March 15, 1991, more than six thousand 9 and 13 year old Taiwanese students took the mathematics and science paper-and-pencil tests. In the following month, one quarter of 13-year-old test takers were randomly selected for further performance assessment.

The major findings in the IAEP were:

- For both age-groups Taiwanese students achieved highest overall mean scores in both subjects.
- The difference between two groups of high achievers and low achievers in the Taiwanese population was larger than in other countries.
- Performance in "Integrating knowlege" was somewhat lower than performance on the memorizing items.
- In Home Characteristics: Taiwanese students have fewer books at home, do much more homework, watch TV less, read less at home ...
- In school activities: Taiwanese students take tests at least once a week, and receive a lot of teacher presentations in their classroom.
- Poor performance was observed in tasks involving manipulation and problem solving skills (Yang, 1992).

The purpose of this study was to identify the main factor influencing our mathematics and science learning in Taiwan, R.O.C.

II. Literature Review

1. Information absorption and problem solving

In discussion of schooling needs, Shymansky and Kyle (1992) argued that the purpose of science education is not merely to help students achieve academically, but to prepare them to lead fulfilling lives. Schooling can no longer function in isolation from the realities of present-day life. Tamir and Amir (1987) also indicated that science learning is more than information absorption; students must be actively engaged in the process of learning so that they can apply their observations, knowledge, and interpretations to solving problems in the world around them.

Problem solving, critical thinking, expertise, and associative and interpretive capabilities develop over time with experience, instruction, and learning (Cole, 1990). In other words, students need some substantial learning experience along with appropriate instruction and proper learning activities to develop their high-order thinking skills. As Crow (1989) suggested, in the general scheme of problem solving, alternative problem representations are always possible. Students must learn to identify the barriers and constraints that must be observed in attaining a solution, and also must learn to identify a set of all possible solution paths or strategies to the goal, so called "problem space", to capture the ingredients of the specific problem. How Taiwanese students would identify their "problem space" in the process of problem solving was our major concern.

2. Child-methods and taught methods

In the article entitled "Societal Differences and Math Understanding" Lin (1988) revealed that there is only one taught alogorithmic system in Taiwan secondary school mathematics. He argued that the taught algorithms were used commonly and badly especially among the lower-level students. Lin also quoted Booth's (1981) interpretation of CSMS (Concepts in Secondary Mathematics and Science Program in England, Hart, 1981) data:

> .... there may be two "systems" of mathematics coexisting in secondary school classrooms: the formal taught system, and a system of child-methods which are based upon a "counting", "adding-on" or "building-up" approach, and by which children attempt to solve mathematical problems within a "human-sense" framework.

In answering the question of why child-methods are so prevalent in English secondary mathematics, Cockcroft (1982) suggested that pupils should be encouraged to approach other calculations, such as those involving percentages, "on their merits" and not be expected to always use a single standard routine. ....pupils should be encouraged to make use of whatever method suits them best. Teachers should also encourage pupils to reflect upon the methods which they develop for themselves.

For the Taiwanese students, a lack of such encouragement, in their primary and secondary mathematics classrooms, means that they do not develop their own methods. Taiwanese students attempt to rely heavily on taught algorithm. More able students might only learn "a set of recipes" in secondary mathematics. Less able students can't even solve relatively easy tasks (Lin, 1988).

What would be the implications of this different problem solving system? Further analysis of IAEP data and a series of follow-up studies will be discussed in the following sections.

III. Methods

The representative sample of 3,300 students from 110 different schools was selected from each population at each age level through the procedure of "two-stage cluster sampling". Specially developed computer software was provided to the participant countries to facilitate sampling and data entry and to ensure uniformity and quality.

The purpose of the IAEP was to compare student achievement in the participating countries and to attempt to identify types of cultural environments and educational practices which appear to be associated with high achievement. Assuring that the assessment results were comparable among countries and that the achievement results provided a meaningful indication of educational performance would be a challenge for any international assessment.

In addition to mathematics and science questions, IAEP included a performance assessment of 13-year-olds. Data was collected in March-April 1991 and the results were reported in February 1992.

The performance assessment was developed for 13-year-old students only and included mathematics and science tasks to enable IAEP participants to experiment with performance assessment in an international context.

A sub-sample of one quarter of the schools involved in the IAEP paper-and-pencil testing was randomly selected for the performance assessment. Likewise the performance tasks were administered to a sub-sample of the students in those schools who had taken the IAEP paper-and-pencil tests, to ensure some common base of experience and permit comparison of written test and performance task results. The participants and assessed skills are indicated in Table 1 and 2.

In order to provide a more detailed picture of the wealth of information produced from the performance assessment, further analysis was conducted on the results produced by Taiwanese students on one of the problem-solving tasks in the mathematics circuit. Results are based on unweighted analysis of student responses and structured and unstructured interviews.

Since interviews were conducted after the official release day of IAEP results (Feb. 5, 1991), it was impossible to interview the original students of the performance assessment, therefore 30 sample students in same age-level were randomly selected from rural and urban schools in the Taipei area for the further studies. The same number of students was randomly selected from each ability level of high, average, and low achievers as identified by the schools.

Table 1. Participants in IAEP Performance Test

Participants	Number assessed in mathematics	Number assessed in science
Canada		
Alberta	179	180
British Columbia	261	240
Nove Scotia	258	258
Ontario-English	326	329
Ontario-French	305	319
Saskatchewan-English	381	377
Saskatchewan-French	224	218
England	158	131
Scotland	283	283
Soviet Union	370	380
Taiwan	315	316

Table 2. The Skills Assessed in the Performance Assessment

Content area	Name of task	Skills assessed
Mathematics	Perimeter	Measurement skills
	Ticket*	Measurement skills and problem solving
	Angles	Measurement skills
	Leaves	Measurement skills
	Pinboard	Geometry concept and problem solving
	Triangles	Geometry concepts
	Scissors	Geometry problem solving
	Clay*	Measurement skills and problem solving
	Water	Measurement skills
Science	Light-up	Physical science concepts and skills
	Circuit	Physical science concepts and skills
	Filter	Nature of science skills
	Magnet	Physical science concepts and skills
	Indicators	Physical science skills
	Float	Nature of science skills
	Tablet in Water	Nature of science skills
	Seeds	Life science problem solving

*Disussed in this paper

Then, the results were compared with a similar study done by Semple (1992), the IAEP national coordinator in Scotland.

IV. Data Collection and Discussion

1. Overall average scores in IAEP Written Tests

For overall average score alone, we may say that Taiwanese students were one of the top-acheivers in both subjects. The best students (the 90th through 99th percentiles) from Taiwan also performed highest among the participating population. But equal concern should given to the lowest performers (the 1st through the 10th percentiles) because they still have to be citizens of a 21st centry technological society. The average scores of those poorest performers from Taiwan ranked almost bottom in the participating populations. (Lapointe *et al.*, 1992)

This strange result may suggest that the low-achievers in Taiwan have some special learning difficulties which do not exist among the students of other countries.

2. Science and mathematics process skills in IAEP Written Tests

In looking for ways to improve students' science and mathematics performance, educators focus as much on the scientific or mathematical processes that students must use as on the content of the specific topics. Science and mathematics educators in many countries now recommend that teachers increasingly focus on process skills through problem solving, communication, and reasoning tasks.

In an attempt to reflect these emphases, IAEP paticipants decided to include questions at three levels of cognitive processing as in Table 3.

About one-third of the questions fell into each of these categories.

Taiwanese students performed relatively better on level 1 and 2 for both subjects and scored relatively lower in level 3 than they did overall, whereas students from Israel, Canada, and France scored relatively higher on this level than they did in science in general; and the students from Switzerland and Scotland scored relatively higher on level 3 than they did overall in mathematics (Lapoite *et al.*, 1992).

In all populations, according to information obtained from student background questions, the vast majority of students (more than 75%) agreed that problem solving is important. Neverthless, more than one half of Taiwanese and Hungarian students viewed mathematics as a memorizing task (Table 4).

3. Problem-solving tasks in IAEP Performance Assessment

Table 3. Levels of Cognitive Processes

Levels of cognitive processes	Science	Mathematics
1	Knows science	Conceptual understanding
2	Uses science	Procedual knowledge
3	Integrates science	Problem solving

Table 4. Percentage of Students Who Viewed Mathematics as a Memorizing Task (Age 13)

Population	Percentage	Jackknifed Standard Errors
Taiwan, R.O.C.	54	1.0
Hungary	54	1.3
Switzerland	34	1.4
Soviet Union	26	1.1
Korea	13	0.7

Measurement and problem solving skills were assessed by tasks "TICKET" and "CLAY" in IAEP Performance Assessment. The performance of Taiwanese students was as follows:

(1) In Task "TICKET": One ticket (5 cm by 7 cm) and a blank sheet of paper (24 cm by 21 cm) were provided to the students to find the greatest number of tickets that could be made from a sheet of paper. Students were also asked to draw lines on the sheet of paper to show how it would divided up to make this number of tickets.

Among all participating populations, about 30% of the students indicated that 14 tickets could be made, whereas only 19% of Taiwanese students could reach that solution (Figure 1).

Fewer (16%) were able to draw the lines showing the correct solution. The majority of them (57%) thought the maximun number of tickets that could be made was 12. In the follow-up studies, many students explained in interviews in this way:

T: How did you get 12 tickets?
S: That was easy. 24 ÷ 5 = 4, and some left, then 21 ÷ 7 = 3, 3 × 4 = 12
T: Don't you think 14 tickets is possible?
S: No, 24 divided by 5 is 4 and 4/5, so you only can get 4. 21 divided by 7 is just 3. 3 multiplied by 4 is 12. It is a correct answer! 14 is impossible.

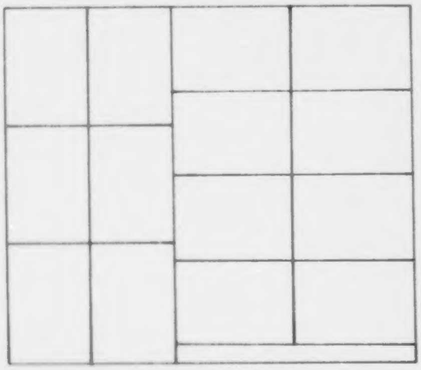


Fig. 1. Solution of Task "TICKET"

Obviously, these student could only rely on taught method or algorithm for problem solving. Probably they lack training in flexible thinking.

(2) In Task "CLAY": A large lump of modelling clay, a two-pan balance, and two masses (20g and 50g) were provided. Students were asked to make a 15g lump of clay using the materials provided and describe how they did it. Simple instructions on how to use the balance were also provided.

Acoording to IAEP data, there was a strong tendency towards the use of estimation rather than mathematically precise methods in participating populations except for Scotland and Taiwan, R.O.C. Credit was given for a clay lump of 15g ± 2g and for describing a feasible method of obtaining it. Scottish and Taiwanese students also achieved highest in percentages of correct responese (Semple, 1992).

4. Problem solving approaches created by Taiwanese and Scottish students in Task "CLAY"

It was very interesting to know that these two populations from different cultures and educational contexts performed in a somewhat similar way in this task. Further studies were conducted in both countries.

Scottish data was obtained from a follow-up study report by Semple (1992).

For both populations two types of strategies were used to produce lumps of plastine of 15g...estimation and precision.

ESTIMATION APPROACHES: Some 25 percent of the Scottish students and 15 percent of Taiwanese students used an estimation approach involving only a 20g mass and the balance to produce a plasticine lump of 20g. Three Types of explanations were given by the students:

> "I made my 15g lump of plasticine by weighing out 20g and
> —removing 1 quarter (Type 1)
> —taking 5g away (Type 2)
> —taking some out (Type 3)

Only 5 Taiwanese students mentioned that they used Type 1. These students probably intended to use their "proportional reasoning" skill to find the solution, and two of them explained:

I rolled the 20g clay in my hands until it became like a long, thin egg-roll. Then I divided it into two halves by estimate, then halved each of them again, and put 3 of them together to make a 15g ball.

Obviously, the method used by these two students was "halving" to solve the problem. This strategy was so-called "building up using halving", a kind of child-method (Hart, 1981; Lin, 1988). One of these two students obtained exactly 15g and the other one 14g, still very close to intended weight.

The other 8 Taiwanese students used the type 2 strategy. Their mathematics used is subtraction, $20-5=15$. But they still had to make an estimation. In the follow-up interview some of these students explained it as "proportional reasoning", like —

I estimate the size of 20g. 5g is 1/4 of 20g. So I could estimate the size of 1/4.

and others, still saying —

15 is less than 20. So, I removed 5 to get 15.

Obviously they are applying the rule of "smaller so subtract".

31 out of 44 Taiwanese students adopting the estimate approach also applied the rule of "smaller so subtract".

The actual weights obtained are indicated in Table 5. More precise measurement was observed in those students who could apply their mathematical ability.

In general, the majority of students in these estimation groups could use only one of the provided masses and apply only simple calculation. It may imply that the students lack flexible thinking ability. But, in the type 1 group, they still could apply their "proportional reasoning skill" to make a relatively precise measurement. However, very few students could be assigned to that category.

PRECISION APPROACHES: Use of 20g mass alone led 22 percent of Scottish students and 5.3 percent of Taiwanese students into precision approaches in which only 20g mass was used. Halving obtained the 20g of plasticine, and they then systematically reduced this to 15g by:

- halving the 20g lump, then halving one of 10g lumps and adding a 5g lump to the first 10g lump, or
- halving the 20g lump, halving both the 10g lump and then combining 3 of the 5g lumps.

This strategy, to use halving to solve problems, is a typical child-method (Hart, 1981; Lin, 1988). 22% of Scottish students used this strategy, whereas only 5.6% of Taiwanese students did.

The most popular precision method involved was the use of the 50g and 20g masses in many different combinations and steps. Ten different strategies were identified from responses of Taiwanese students. Their "problem reformulation" and "planning" patterns for each were summarized in the following.

STRATEGY 1: Put 50g and 20g masses in op-

Table 5. Actual Weights (g) of Clay Obtained by Estimation of Taiwanese Students (N = 282)

Types	Explanations	N	M	SD	% in Pop.
1	remove one quarter	5	14.6	1.0	1.6
2	remove 5g	8	17.1	2.3	2.6
3	remove some	31	18.3	1.9	10.1

posite pans on the balance to obtain a 30g plasticine, and then halve it to obtain two 15g clay balls. 72 students applied this approach to reach the solution.

STRATEGY 2: Put a 50g mass in one of the pans to obtain a 50g plasticine. Replace the 50g mass with a 20g mass, then remove 30g plasticine from the 50g plasticine. This is then halved to obtain two 15g lumps. This approach was used by 10 students.

STRATEGY 3: Use both 50g and 20g masses to produce a 70g plasticine. Halve it to obtain two 35g plasticines. Then, a 20g mass is weighed against one of the 35g plasticines removed from this lump to obtain a 15g lump. 4 students applied this approach.

STRATEGY 4: A variation of strategy 3. In the third step instead of a 20g mass a 50g mass is weighed against the 35g lump to produce a 15g lump. One student used this approach.

STRATEGY 5: Put the 50g and 20g masses in opposite pans to produce a 30g lump. Then put this 30g lump and 20g mass in opposite pans to produce a 10g lump. Repeat same step once to obtain another 10g lump. Halve one of the 10g lumps. Finally combine a 10g lump and a 5g lump. 5 students used this approach to produce a 15g lump.

STRATEGY 6: Use the 50g mass to produce a 50g lump. Halve it to obtain a 25g lump. Then the 20g mass is weighed against one of the 25g lumps to remove a 5g clay lump. Finally the 5g lump and 20g lump are put in opposite pans on the scale. The 15g lump is removed from the 20g lump. One student used this complicated approach.

STRATEGY 7: A 20g mass is used twice to produce two 20g lumps. Put them together in one of the pans on the scale. Put a 50g mass on the opposite pan to produce a 10g lump. Repeat the procedure to produce another 10g lump. Halve one of the 10g lumps. Finally put the 10g and 5g lumps together to reach the solution. 8 students applied this approach.

STRATEGY 8: Put a 50g mass on one of the pans on the scale to produce a 50g lump. Use a 20g mass to obtain a 20g lump. Then the 20g lump is halved. Put 10g and 50g lumps together to make a 60g lump. Then the 60g lump is halved twice systematically to produce a 15g lump. Only one student applied this approach.

STRATEGY 9: Put 50g and 20g masses in opposite pans on the scale to produce a 30g clay lump. Then the 20g mass is weighed against the 30g lump. A 10g lump is removed from the 30g lump and a 20g lump is left on the pan. Both the 10g and 20g lumps are halved to produce 5g and 10g lumps. Put them together to obtain a 15g clay lump. One of the Taiwanese students used this approach.

STRATEGY 10: The 20g mass is used three times to produce three 20g lumps. Put them together on one of the pans on the scale. Put a 50g mass on the opposite pan to produce a 10g lump. Repeat the process. Two 10g lumps are obtained. Halve one of the 10g lumps. Put a 10g and 5g lump together to reach the solution. This extremely complicated approach was used by one student.

Twelve different approaches applied by Taiwanese students are summarized in Figure 2.

As shown in Figure 2, halving procedure was used commonly during the problem solving. Students also could use two provided masses and clay lumps in different combinations in two balance pans. The hint may came from the instruction in the test booklet. It said:

> In each pan of the balance, you are permitted to put modelling clay alone, metal masses alone, or a combination of the two. When the arrow on the balance comes to rest on the centre line, the contents of the two pans have the same mass. You can adjust the amount of modelling clay or the number of metal masses you are using to make the pans balance.
> There is a wire lever on the left side of the balance that helps the scale come to rest. Push this lever to the right and the scale will come to rest.

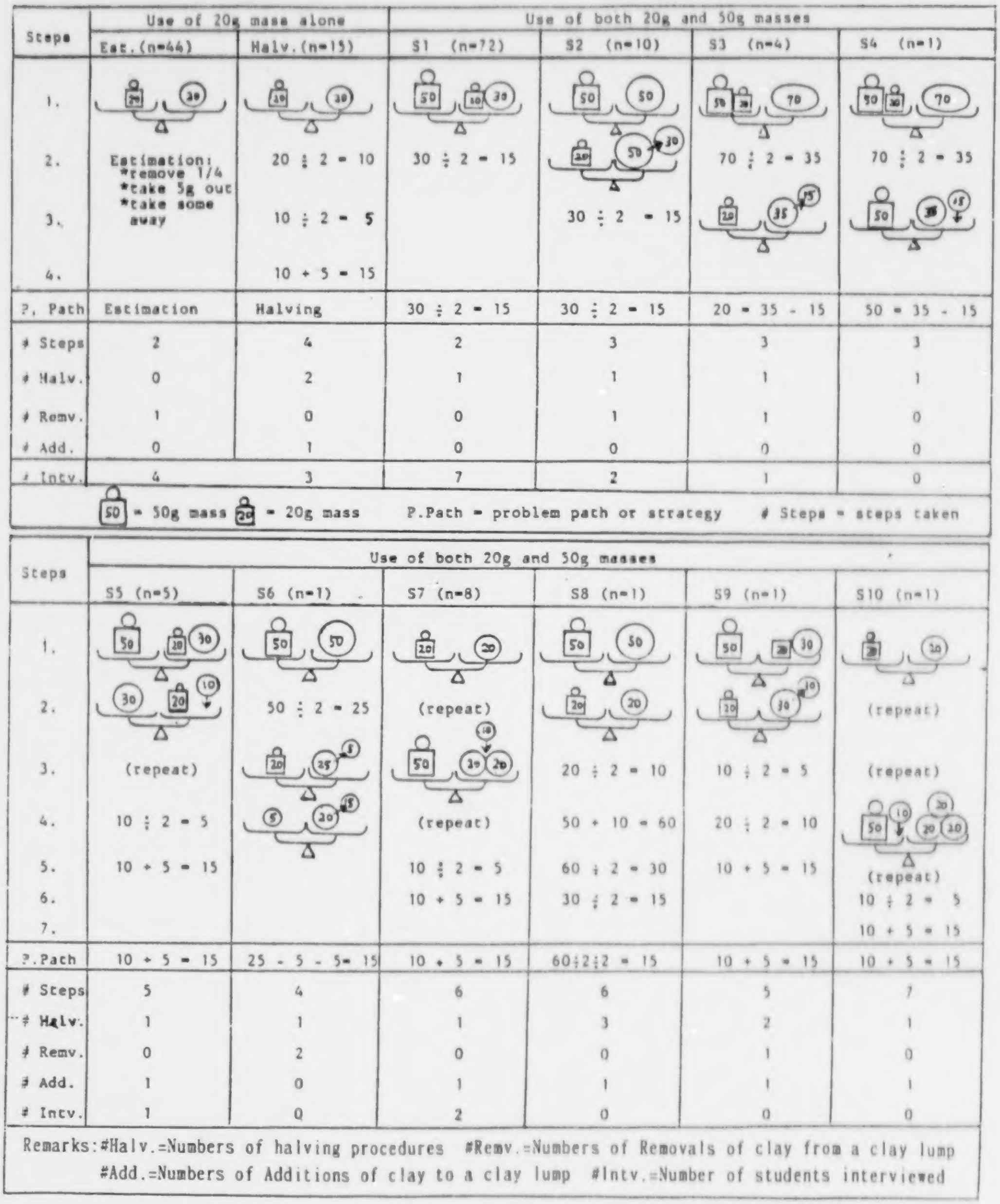
In the follow-up interview, very few students said that this was a "taught-method". Instead, most of them took pride in saying: "I thought it out".

T: How did you think of putting a 50g mass in one pan, and a 20g mass in the other?
S: That was the only way I could get a 30g lump.
T: Why 30?
S: 30 can halve to make 15.
T: Did your teacher teach you that way?
S: No, I thought it out by myself.

Another girl student who applied strategy 3 said, "It was just like a mathematics game. You want me to find 15. But I only have 50 and 20. And you want me to use that balance. I just take them,... add them, subtract..., or divide it in halves. I played a game of numbers."

A boy who applied strategy 7 expressed his feeling:

T: You took 6 steps to reach the solution. Was it a difficult task?



Steps	Use of 20g mass alone		Use of both 20g and 50g masses			
	Est.(n=44)	Halv.(n=15)	S1 (n=72)	S2 (n=10)	S3 (n=4)	S4 (n=1)
1.						
2.	Estimation: *remove 1/4 *take 5g out *take some away	20 ÷ 2 = 10	30 ÷ 2 = 15		70 ÷ 2 = 35	70 ÷ 2 = 35
3.		10 ÷ 2 = 5		30 ÷ 2 = 15		
4.		10 + 5 = 15				
?, Path	Estimation	Halving	30 ÷ 2 = 15	30 ÷ 2 = 15	20 = 35 - 15	50 = 35 - 15
# Steps	2	4	2	3	3	3
# Halv.	0	2	1	1	1	1
# Remv.	1	0	0	1	1	0
# Add.	0	1	0	0	0	0
# Intv.	4	3	7	2	1	0

50 = 50g mass 20 = 20g mass P.Path = problem path or strategy # Steps = steps taken

Steps	Use of both 20g and 50g masses					
	S5 (n=5)	S6 (n=1)	S7 (n=8)	S8 (n=1)	S9 (n=1)	S10 (n=1)
1.						
2.		50 ÷ 2 = 25	(repeat)			(repeat)
3.	(repeat)			20 ÷ 2 = 10	10 ÷ 2 = 5	(repeat)
4.	10 ÷ 2 = 5		(repeat)	50 + 10 = 60	20 ÷ 2 = 10	
5.	10 + 5 = 15		10 ÷ 2 = 5	60 ÷ 2 = 30	10 + 5 = 15	(repeat)
6.			10 + 5 = 15	30 ÷ 2 = 15		10 ÷ 2 = 5
7.						10 + 5 = 15
?.Path	10 + 5 = 15	25 - 5 - 5= 15	10 + 5 = 15	60÷2÷2 = 15	10 + 5 = 15	10 + 5 = 15
# Steps	5	4	6	6	5	7
# Halv.	1	1	1	3	2	1
# Remv.	0	2	0	0	1	0
# Add.	1	0	1	1	1	1
# Intv.	1	0	2	0	0	0

Remarks: #Halv.=Numbers of halving procedures #Remv.=Numbers of Removals of clay from a clay lump #Add.=Numbers of Additions of clay to a clay lump #Intv.=Number of students interviewed

Fig. 2. Summary of strategies achieved by Taiwanese students in Task "CLAY"

S: No, it was easy. I just tried to make my measure more precise.

T: What do you mean?

S: I measured twice to produce two 20g lumps, and used them to produce two 10g lumps. I did it many times in small steps so the result would be more precise.

T: Why did you have to produce a 10g lump?

S: Because, 10 is a good number.

T: Why?

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S: 10 can be halved to make 5.
T: Did your teacher teach you any formula to answer a similar question?
S: .....No.
T: Would you like to be tested in this way in school?
S: Yes, I would. It was a lot of fun. I thought out my own way to solve the problem.

Some 37 percent of assessed Taiwanese students could think out their own way to solve the problem. They appeared not to rely on their taught algorithm, just applying "halving" and some simple addition and subtraction skills. The problem barrier or constraint in this task was the lack of a 15g mass. The alternative problem representation found by these students was using or combining provided masses to produce 30, 35, or 10g clay lumps. The "problem space" of this task was relatively wider. It allowed students to create many different paths or strategies to teach the solution. The method used still could be identifyed as a self-created method or "child-method".

5. *Comparative studies on performances of Taiwanese and Scottish students in IAEP*

The strategies applied by Scottish students in many approaches were very similar to those of Taiwanese students. But, the distribution of number of students in each of the approaches differed very much.

From data indicated in Table 6, about the same proportions of both populations used a "precision" method. However, among them only 5% of the Taiwanese students, as compared with 22% of Scottish students, used a so-called "child-method" by obtaining a 20g lump, then reducing in systematically to 10g and 5g. Furthermore, the "Estimation method" was more commonly used in the Scottish population (25%, compared with 16% in the Taiwanese population). These facts may suggest that the "child-method" or "own created method" is more popular in the schools of Scotland than in those of Taiwan. The other remarkable difference was the proportions of "other/no response". A considerable number (42%) of Taiwanese students (only 27% of the Scottish) could not properly respond to the question in this task. A typical response of students in this group in their interviews was:

Table 6. Distribution of Percentages of Students in Problem Solving Approaches.

Approaches	Taiwanese	Scottish
Precision	42	48
• Used 20g mass only	(5)	(22)
• Used 20 & 50 masses	(37)	(26)
Estimation	16	25
Others/No response*	42	27
TOTAL	100	100

*Incorrect responses included

T: Is this task (CLAY) too difficult for you?
S: I don't know.
T: Do you understand the question?
S: Yes, but,....my teacher never taught us how to answer that kind of question.

Obviously, Taiwanese students, especially low-achievers have seldom been encouraged to used thier own-created method to solve the problem encountered. Another special finding concerned 37% of the Taiwanese population and 26% of the Scottish students. They used both 20 and 50g masses and successfully solved the problem. These students could be seen as the "top" students in their student population. They could probably apply "taught method" and also could create their own way. Then, their written test scores were compared. Results of *t*-test are in Table 7.

Table 7 indicates that Taiwanese students achieved significantly higher ($p < .01$) than that of the Scottish population in all variables in written tests. This situation may suggest that Taiwnaese students were more "successful test takers".

In the IAEP written test, there were 7 test items designed to assess "measurement skills and problem solving". Significant differences between the two populations were observed in 6 out of the 7 items (Table 8). All these items concerned computation of areas, perimeters, or sides of a rectangle, square, or circle. Students may rely on "taught method or formula" to compute and get a correct answer. This evidence may also suggest that Taiwanese students were well-trained to "beat" a test, or examination.

But, in a written test-item 2M1-8 (Fig. 3), which was also designed to assess algebra problem solving similar to that of the performance task "CLAY", the Scottish population achieved significantly better scores than the Taiwanese students by 66.5 to 61.3%. In this item, there was a diagram of a balance with a 1 kg mass and a half brick on one of the pans and 1 brick on the other. Students were asked to com-

Table 7. Comparison of Written Test Scores in IAEP between "Top-students" of Scottish and Taiwanese Groups

Dependent variables		Taiwan (n = 127)		Scotland (n = 93)		t value
		M	SD	M	SD	
Process	PK	24.25	3.69	19.28	5.25	7.28**
	CU	21.96	3.55	18.51	4.33	6.29**
	PS	20.46	4.29	17.41	4.35	5.17**
Content	NUM	23.61	3.95	19.30	4.59	7.29**
	MEA	10.72	2.75	8.46	2.85	5.89**
	GEO	9.98	1.69	8.99	2.07	3.78**
	DAT	8.31	1.19	7.99	1.49	1.71*
	ALG	13.09	2.66	10.12	3.61	6.71**
Total		66.67	10.90	55.19	12.95	6.94**

**$p<.01$, *$p<.05$

Table 8. Topic Percents Correct and Standard Error (SE) of Taiwanese and Scottish Students in Topic: MEA PS

Test items	Short text	Taiwan, R.O.C.		Scotland	
		M	SE	M	SE
2M1-9	Perimeter = 56cm	58.4	1.3	44.6	1.7
2M1-18*	Width-6cm	57.2	1.4	57.4	1.9
12M2B-15	Length = 4, Width = 2	53.5	1.6	49.3	1.7
2M3-9	L-12, W = 12 are not possible	76.4	1.2	58.3	1.9
2M3-18	The shaded region = .85	59.2	1.4	33.2	1.3
2M3-19	Height of solid = 2FT	60.3	1.5	40.7	1.8
2M4-18	Have different perimeter, same area	66.5	1.1	35.5	1.5
MEA PS	(7 ITEMS)	61.7	1.0	45.6	1.3

*Data were provided by IAEP.

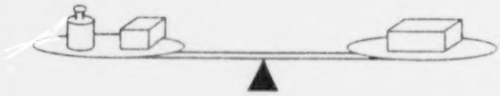

Fig. 3. IAEP item 2M1-8

pute the weight of the brick. One of the experienced Taiwanese mathematics teachers explained, "Most above-average students could produce a formula : $1\text{kg} + \frac{1}{2}X = X$, but below-average students couldn't."

There was a difficulty in learning how Scottish students dealt with this problem. But, we still could assume that "child-methods" were more commonly applied among the Scottish population.

6. Further analysis on problem solving strategies in Task "CLAY" performed by Taiwanese students

As shown in Figure 2, eleven different precision strategies were produced among Taiwanese students. Some of them took only two steps to complete the task. However, some of them took six to seven, rather complicated steps to reach the same solution. Apparently, the more steps taken, the lower the effectiveness. In other words: clever students may take fewer, more effective steps.

In order to study the relationship between students' performance in the Task "CLAY" and their achievement on the Written Test, Taiwanese students were put in 6 groups:

(1) Estimation group: Use 20g mass to produce 20g lump, them reduce to 15g by estimation. 44 cases observed.

(2) Use 1 mass (20g) only: systematic halving procedures to obtain 20g, 10g, then 5g lump. Apply typical "child-method". 15 cases fell in this group.

(3) Use a combination of two masses, taking only 2 steps to reach the solution. This most effective approach led 72 students to complete the task.

(4) Also used 2 masses and took 3 steps to complete the task. 15 cases fell in this group.

(5) Took 4 or more steps to reach the solution. 17 cases identified.

(6) Others, including "no response", and failed to plan a reasonable approach, 119 cases.

The results of ANOVA and the follow-up analyses with Duncan's procedures are summarized in Tables 9 and 10. Significant differences ($p<.001$) appeared among the six groups for all dependent variables. Further multiple range testing indicated that there were significant differences ($p<.05$) among the groups:

(1) Precision approach group >* Estimation group >* Others in each of the dependent variables of PK, CU, GEO and DAT.

(2) Precision approach group >* Estimation group = others in each of the variables of PS, NUM, MEA, and ALG.

(3) Surprisingly, there were no significant differences among 1M, 2S, 3S, and MO groups. 1M and 2S groups created relatively effective approaches for solving the problem, whereas 2S and MO groups used more steps and rather complicated and ineffective approaches. All three students randomly selected from MO group said in almost the same way at their interviews:

> After the test I thought out a more effective and much simpler way. I was so nervous, I put the masses on pans here and there in different combinations, until, finally I came across the correct answer. I will do much better next time. I believe I can do it in a more systematic way.

Probably it was fair to say that those MO students just lacked experience associated with appropriate instruction. They could do better if they had more opportunities for practice. Problem solving skills do develop over time with experience, instruction, and learning (Cole, 1990).

Table 9. Comparison of Performance in the Task "CLAY" and the Achievement in Written Test (N=282)

Dependent variables	EST.		Precision approaches										F Ratio
			1 mass		2 steps		3 steps		more steps		others		
	N=44		N=15		N=72		N=15		N=17		N=199		
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	
Process													
PK	18.2	6.6	23.0	3.6	24.0	3.9	24.8	2.7	25.0	2.3	16.0	7.4	22.67***
CU	17.5	4.7	21.1	3.2	21.8	3.6	22.3	3.1	22.9	3.2	15.4	5.5	24.14***
PS	14.3	5.4	19.0	4.9	20.2	4.2	20.9	4.0	21.4	3.2	12.9	6.2	24.32***
Content													
NUM	19.4	5.9	22.1	3.9	23.4	3.7	24.0	3.7	24.2	4.1	16.6	6.3	20.24***
MEA	7.0	3.3	9.8	2.9	10.5	3.0	10.9	2.3	11.0	2.3	6.0	3.8	22.80***
GEO	8.0	2.6	9.6	1.5	9.9	1.7	10.0	1.4	10.2	1.0	6.9	2.9	19.25***
DAT	6.9	1.8	8.4	0.9	8.2	1.3	8.5	0.7	8.6	0.4	6.1	2.2	18.53***
ALG	8.8	4.0	12.2	2.9	12.9	2.6	13.5	2.0	14.1	1.5	8.0	4.4	25.03***
PS	14.3	5.4	19.0	4.9	20.2	4.2	20.9	4.0	21.4	3.2	12.9	6.2	24.32***

$^{***}p<.001$

Table 10. Multiple Range Test: Duncan's Procedure

MEANS

PK	UC	GEO	DAT
16.0	15.4	6.9	6.1
18.2	17.5	8.0	6.9
23.0	21.1	9.6	8.2
24.0	21.8	9.9	8.4
24.8	22.3	10.0	8.5
25.0	22.9	10.2	8.6

	OTH	EST	1M	2S	3S	MO
OTH						
EST	*					
1M	*	*				
2S	*	*				
3S	*	*				
MO	*	*				

*$p<.5$

MEANS

PS	NUM	EMA	ALG
12.9	16.6	6.0	8.0
14.3	18.4	7.0	8.8
19.0	22.1	9.8	12.2
20.2	23.4	10.5	12.9
20.9	24.0	10.9	13.5
21.4	24.2	11.0	14.1

	OTH	EST	1M	2S	3S	MO
OTH						
EST						
1M	*	*				
2S	*	*				
3S	*	*				
MO	*	*				

*$p<.5$

V. Implications and Conclusions

Problem solving skills of Taiwanese 13-year-old students were analyzed in comparison with Scottish students of the same age, based on IAEP Performance Assessments and Written Tests conducted in 1991. The results could be summarized as follows:

1. For overall scores on written tests, Taiwanese students performed as one of the highest achievers among twenty participating countries. But they scored relatively low in "integrating learned knowledge" and "problem solving" test items than they did overall.
2. Over half (54%) of the Taiwanese students believed "learning math is mostly memorizing".
3. From performance assessment tasks, Taiwanese students showed a strong tendency to rely on "taught method" in the problem solving process, especially among low-achievers. They have seldom been encouraged to use their own-created method of problem solving.
4. Although the top students still could develop their own method and finally solve the problem, yet most of them performed some-what ineffectively.

In general, compared with the performance of Scottish students, Taiwanese stuednts attempted to rely heavily on taught methods or formulas, whereas Scottish student could develop their own method to solve the problem. Why are "taught-methods" so prevalent in Taiwan? Why have Taiwanese students not been encouraged to develop their own method or "child-method"? Lin (1988) explained in his paper:

> Taiwanese students attempt to rely heavily on taught algorithms in secondary school mathematics, ...The reasons suggested as to why this is so may be lack of time and lack of relevance to the demands of the entrance test.

In general, formally taught algorithms are more applicable to entrance examination test-items than informal methods. Students are trained to do tasks as fast as possible. They have seldom been encouraged to develop their creativity. Under the pressure of the entrance examination, there is no room for students to create their own methods or to develop their imagination in problem solving.

Results of this study strongly agreed with research done by Lin (1988). In concluding his paper Lin said:

> The price Taiwan secondary mathematics students have paid is very high. For more able students, they might only learn "a set of recipes" in secondary mathematics.... For less able stu-

> dents, they can't even solve relatively easy tasks...(p.495)

In fact, the price Taiwanese students paid was more than that. According to IAEP results, mainly based on information obtained from the background questions, Taiwanese students may have lost their happy childhood by —

- frequent tests in many subjects given during school days.
- too much homework every day.
- going to extra classes after school almost every day.
- less leisure reading at home.
- less reading for fun.
- less time to watch TV.
- fewer leisure activities initiated by themselves.

The relatively lower percentage of Taiwanese students who have positive attitudes toward mathematics and science may be another evidence (Lapointe *et al.*, 1992). The purpose of science education is not merely to help students achieve academically, but to prepare students to lead fulfilling lives. How citizens think, what they value, how analytical and critical they can be, how they question and reflect — these are among the true measures of successful schooling. Thus, the most important issue in Taiwan, is how to get rid of the pressure of the entrance examination, and also how to develop the creative abilities of students, not only of the more able, but also of the less able. Creativity might mean different things to students of different abilities. This is what we must do to prepare all of today's youth for tomorrow's world.

References

Booth, L. (1991). Child-method in secondary mathematics. *Educational Studies in Mathematics, 12*, 29-41.

Cockcroft, W. (1982). *Mathematics Counts*. London: Her Majesty's Stationery Office.

Cole, N. (1990). Conceptions of educational achievement. *Educational Researcher, 19*(3), 2-7.

Crow, L. (1989). *Enhancing critical thinking in the sciences.* Houston, Texas: Society for College Science Teacher.

Hart, K (1981). *Children's understanding of mathematics: 11-16.* London: John Murray.

Lapointe, A., Askew, J., & Mead, N. (1992). *Learning Science* (Report No. 22-CAEP-01). Princeton, N.J.: Educational Testing Service.

Lin, F. (1988). Societal differences and their influences on children's mathematics understanding. *Educational Studies in Mathematics, 19*, 471-497.

Murphy, P. & Gott, R. (1984). *Science: Assessment framework age 13 & 15.* Assessment of Performance Unit, Science Report for Teachers: 2. Department of Education and Science Welshi Office.

Scottish Education Department (1988). *Mathematics: Second survey 1988.* Edinburgh: Assessment of Achievement Programme.

Semple, B. (1992). *Performance assessment: An international experiment* (Report No. 22-CAEP-06). Princeton, N.J.: Educational Testing Service.

Shymankey, J. & Kyle, W. (1992). Establishing a research agenda: Critical issues of science curriculum reform. *Journal of Research in Science Teaching, 29*, 749-778.

Tamir, P. & Amir, R. (1987). Inter-relationship among laboratory process skills in biology, *Journal of Research in Science Teaching, 24*, 137-143.

Wang, K. *et al.* (1985). *A study of present situation of science education in Taiwan, R.O.C.* Taipei: Science and Technology Advisory Goup, Executive Yuan. (In Chinese)

Yang, J. (1992). What could be learned from 1992 IAEP? *Science Education Monthly, 149*, 2-31. (In Chinese)

Yang, J. (1988). *A survey of science teaching in high schools in Taiwan, R.O.C.* Taipei: Science Education Center, National Taiwan Normal University. (In Chinese)

1991年國際教育進展評鑑中我國和蘇克蘭學生解題能力表現的比較研究

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摘　要

由1991年國際教育進展評鑑(IAEP)中我國學生在筆試及實作測驗中的表現，研討考試文化下，我國學生的解決問題能力。除IAEP各項測驗資料外，進一步以晤談法深入探討學生們在解題過程中的思考模式和解題策略。再用IEAP參加國之一蘇克蘭所做相類似的研究資料(Semple, 1992)，以比較二國不同文化下學生的解題策略。結果發現我國學生對“被教方法”有較大的依賴性，而蘇克蘭的學生則較能自創策略以解決問題。

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D. Heading

The main divisions are suggested to be arranged as follows: INTRODUCTION, METHODS, RESULTS, DISCUSSION, CONCLUSION (if any), ACKNOWLEDGEMENTS, and REFERENCES.

E. Unit of Measure

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F. Footnotes

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International standards on nomenclature should be used. The following guide is recommended:

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Standard abbreviations for certain substances and units of measure do not need to be defined. Nonstandard abbreviations should be spelled out on first usage. Both standard and nonstandard abbreviations should also conform to international standards. Authors should refer to: *IUPAC Manual of Symbols and Terminology for Physicochemical Quantities and Units.* 1970. Butterworths, London, England; *National Bureau of Standards Special Publication 330. 1977.* Or *Pure and Applied Chemistry.* 1970, 21, 3-44; *Quantities, Units and Symbols.* 1971. Royal Society Symbols Committee, Royal Society, London.

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A Pilot Study: The Effects of Computer Animation and Television Viewing Behavior on Intrinsic Motivation in Computer-Based Instruction

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ABSTRACT

The purpose of this study was to examine the effects of computer animation and television viewing behavior on intrinsic motivation in a computer-based instructional lesson. A modified definition of Rubin's definition for television viewing behavior was employed in this study. Forty-seven undergraduates were involved. There were four major findings: (1) subjects' intrinsic motivation was moderately higher if the graphics of the CBI lesson were animated; (2) subjects' television viewing behavior rated as "to learn" had moderately higher intrinsic motivation; (3) the higher ranking for "arousal", the lower the academic achievement; and (4) the more the time spent watching TV before college, the lower the academic achievement.

Key words: animation, television viewing behavior, intrinsic motivation and CBI

I. Introduction

Over the past four decades, two technological devices have grown exponentially: television in the first two decades and computers in the last two (Becker & Sterling, 1987). Making sense of the coming of these two devices into our students' lives, many studies have investigated their impacts from a pedagogical point of view. Rubin (1977) reported that television was an important medium and viewing television was an important activity to many individuals, especially to younger children, who appeared to have the greatest affinity with the medium. He also discovered that television claimed the attention of American school children for approximately two-and-a-half hours to four-and-a-half hours per day. Many studies (e. g. Kozma, 1991; Kodaira, 1986; Lyle, 1972; Singer & Singer, 1983) have focused on the amount of time spent on television viewing, preference in TV programs, and the influence on reading habits, enthusiasm in tasks, and ability to be imaginative. One might ask whether the effects of students' watching TV influence not only their present academic performance but also their future learning ability. Kozma emphasized that television might affect cognitive structures and processes. It simultaneously employs linguistic and pictorial symbol systems which are transient and able to depict motion. This transience may have some advantages in the development of dynamic mental models. He concluded that when viewing television with a purpose, people will attend more thoughtfully, constructing more detailed, elaborate representations and drawing more inferences from them.

As mentioned above, in Kozma's study, we can see that animation is one of the important features of TV programming. Although Clark (1985) contended that computers did not make learning more effective, he argued that it was the method employed in a computer-based learning environment, not the medium, that influences learning outcomes. From his point of view, focusing only on the machine rather than how to make it fit into students' learning characteristics is useless. The promising design of new computer-based instructions which integrate activities with students' learning characteristic is an efficient way in which computers can be used in the classroom. Since most educators should agree that learning can be viewed as an active, constructive process whereby the learner strategically manages the available cognitive resources to create new knowledge by extracting information from the environment and integrating it with information already stored in memory, the process of cognition is sensitive to characteristics of the external environment. Therefore, it is believed that computer-based instruction may assist students' learning. So much research has been conducted to investigate the effects of animation in CBI lessons on learning (King, 1975; Moore, Nawrocki, & Simutis, 1979; Reed, 1985; Rieber, Boyce, & Assad, 1990). Rieber, Boyce, & Assad, in their study of the effects of animated visuals on children's learning of Newton's law of motion, claimed that animated graphics successfully promoted incidental learning. From their work, it was pointed out that the CBI lesson held intrinsically motivating appeal for the students, which could be demonstrated from the fact that more students chose to stay on task longer than to play a word-find puzzle for the post-lesson activities. Lepper & Gurtner (1989) found that various forms of computer use are likely to have impact on different children's learning, motivation, and social behavior. And, despite dramatic increases in the types of educational programs available, attention to individual differences among children has remained limited to variations in their knowledge such as: cognitive abilities, motivation, interests, creativity (Snow, 1986), and their general academic ability (Lepper & Gurtner). Therefore, an increased understanding of individual differences such as feeling, habit, and personality, has become necessary. Although there was no consistent evidence to strongly suggest that animation, from instructional television, contributed to learning (Chu & Schramm, 1967), many computer-based instruction CBI lessons still used animation in the development of the software, which was suggested by most of the books related to CBI design (Criswell, 1989).

It is far from obvious that the pedagogical and technological innovations available have a good effect on students' learning. Many educators believe that motivation can help us understand and explain certain facts about students' behavior and learning. Moreover, from the pedagogical point of view, motivation is very important because it affects both teaching and learning. On the hand, motivation is one of the purposes of teaching. We want our students to become interested in the materials we teach and to retain the concepts they have learned. On the other hand, motivation is one of the factors that determine whether students will achieve the knowledge, or skills that we want them to have. These statements can be confirmed by Ringness (1965), as well as Ugurogulu and Walberg's (1979) studies. Ringness looked at motivational differences in students of the same IQ level and measured the motivation of the two groups (over-achievement and under-achievement both with IQ 120) using various tests and an interview. It turned out that the higher-achieving students had higher motivation. He claimed that motivation accounts for success academically. Ugurogulu and Walberg analyzed correlation coefficients between motivational measures and academic achievement and concluded that high levels of motivation lead to high achievement. At the same time, they claimed that high levels of achievement lead to high levels of motivation. From their studies, although the cause and effect are not clear to us, there is no doubt that motivation and academic achievement have a positive correlation.

From the psychological point of view, a close look at television and the computer's roles in motivating students' learning will benefit educators. However, only a few, if any, studies have investigated this problem and none have included college-level students. Therefore, this paper attempted to study the effects of computer animation and television-viewing behavior on intrinsic motivation in computer-based instruction. As illustrated above, the focus of the present study was directed toward the following questions:

1. Does animation increase learner intrinsic motivation in CBI?
2. When or under what conditions would TV viewing behavior, regardless of animation, increase learner intrinsic motivation in CBI?
3. Does TV viewing time or TV viewing behavior influence the effects of animation on intrinsic mo-

tivation in CBI?

4. Does TV viewing time or TV viewing behavior correlate with students' performance on achievement tests in CBI?

II. Methods

This study was experimental. It employed a randomized complete-block design with classes of students as the blocks. One block contained students who majored in the mathematics department of the school of education and the other block contained students who majored in educational computing. Moreover, each block was further divided into a control group, without animation in their CBI lesson and a treatment group, with animation in their lesson. Subjects in each block were randomly assigned to either group. The TV-viewing behavior of subjects in both groups was assessed by the pre-questionnaire. Intrinsic motivation was measured by the number of sections subjects completed, the time spent on the learning task, and the scores on the post-questionnaire at the end of the CBI lesson.

We posed six alternative hypotheses for whatever questions were under study. Guided by these hypotheses, we measured variables and used them to test the alternative hypotheses.

H1 Animation in CBI lessons has effects on subjects' intrinsic motivation.
H2 TV viewing behavior has effects on subjects' intrinsic motivation.
H3 TV viewing behavior influences the effects of animation on intrinsic motivation.
H4 TV viewing time influences the effects of animation on intrinsic motivation.
H5 TV viewing behavior has effects on subjects' achievement in CBI lessons.
H6 The number of hours spent watching TV per day before college has negative effects on subjects' achievement in CBI lessons.

1. Subjects

The sample contained 47 undergraduate students at Purdue University. A total of 34 of them were taken from students who majored in educational computing. The rest were taken from students who majored in the mathematics department of the school of education. Those subjects were voluntary but extra points were provided for participation. Before the CBI lesson, they were told that they could terminate the lesson at any time.

2. Materials

The CBI used was a modified version of part of computer courseware that was developed by Feng-Jui Hsieh using authorware professional v1.6. The original program was developed through the use of a systematic design model—Dick & Carey CBT design model—and it introduced a mathematical concept "Venn diagrams". The development of the courseware was separated into five stages and formative evaluation was conducted in each stage.

The concept of the Venn diagram uses geometric figures to represent sets. The location of the geometric figures indicates the relationships of the sets. The operations of sets can be illustrated in the regions of the Venn diagrams. The Venn diagram was chosen because its content was suitable (moderately difficult) for the college level students. Prior to the development of the CBI lesson, an exploratory study was conducted by the designer. The exploratory study revealed that students (with similar background as subjects in this study) were somewhat confused about the Venn diagram.

The difficulty of the lesson increased as the lesson progressed. In the first two sections, the learning material was considered as moderately easy for the learners in this study. From the third section on, it became gradually more difficult. The last three sections were considered to be very difficult for the learners.

The content covered in the CBI lessons were:

(1) The introduction of Venn diagrams.
(2) Using Venn diagrams to represent the relationships of sets.
(3) Set expressions for Venn diagrams.
(4) Venn diagrams for set expressions.

After the tutorial part of each section, the program presented several practice problems. Informative feedback about the correctness of the problems was given to the students. After they had completed the practice problems, several quiz problems were presented by the computer to measure what they had learned. The answers to the problems were not given to the learners immediately after they had answered the questions.

3. Instruments

Two questionnaires, a pre-questionnaire and a post-questionnaire, were designed. The purpose of the pre-questionnaire was to ascertain subjects' TV viewing motive and the amount of time subjects spent watching TV and MTV. To assess subjects' TV viewing motive, a model was selected from Rubin's definition (1977) and modified as follows:

To learn
- (1) so I can learn about things happening in the World
- (2) so I can learn how to do things I haven't done before
- (3) because it teaches me things I don't learn in school
- (4) because it helps me learn things about myself
- (5) so I could learn about what could happen to me
- (6) because it shows how other people deal with the same problems I have

To pass time
- (1) because it's a habit
- (2) because I just like watching
- (3) because I just enjoy watching
- (4) when I have nothing better to do
- (5) because it passes the time away
- (6) because it gives me something to do

For companionship
- (1) so I won't be alone
- (2) when there's no one to talk to or play with
- (3) because it makes me feel less lonely

To forget
- (1) so I can forget about school and home work
- (2) so I can get away from the rest of the family
- (3) so I can get away from what I'm doing

For arousal
- (1) because it's thrilling
- (2) because it excites me
- (3) because it stirs me up

For relaxation.
- (1) because it relaxes me
- (2) because it calms me down when I'm angry
- (3) because it's a pleasant rest

In Rubin's study, principal-factor analysis and inter-item correlation analysis were conducted for all 24 items in all categories. It was found that, in each category, all the items accounted for a single TV viewing motive. Therefore, the items in each category did not need to be analyzed separately. Hence the pre-questionnaire, in this study, asked subjects to rank their preferences among the following alternatives:

To pass time
To learn
For companionship
To forget
For arousal
For relaxation

The purpose of the post-questionnaire was to assess whether subjects would like to use computers to learn mathematics, whether they believed computers were helpful in the learning of mathematical concepts, and whether they would like to continue learning with this approach. It was used as a measure of intrinsic motivation. Each alternative of each statement was assigned a point value from 1 to 5. The response of "strongly disagree" was assigned a point value of 5, "disagree" was assigned a value of 4, and so on. A subject's score was determined by summing up the point values for each statement. Appendix gives both the pre-questionnaire and the post-questionnaire.

4. Procedures

Students enrolled in a computer course and in a mathematics course were asked to volunteer for this study with an incentive of extra credit. The subjects were asked to plan for at least a half hour for the activity. Individual appointments with the researcher to participate in the study were utilized. As the subjects arrived in the laboratory, they received an instruction sheet. The instruction included:

- (1) Appreciation of their participation
- (2) The total number of sections (7)
- (3) That they needed to complete two sections in order to receive extra credit
- (4) The choice of quitting the learning program at the end of each section
- (5) Asking them to fill out the pre-questionnaire
- (6) Telling them to start the computer program

After each section, students were prompted to determine whether they wanted to continue the lesson. The post-questionnaire was displayed on the screen at the time students chose to quit the program. The answers to post-questionnaires, the sections completed, and the time spent on the program were automatically recorded. The whole activity took about one hour if students finished all seven sections.

III. Data Analysis and Result

This study had the usual CBI feature of free time to learn the lesson and answer the questions. It is important that the results were neither related directly to any teaching process nor to any interaction between teachers and students. Moreover, the unit of analysis for this study was the subjects in different blocks, not the individuals. Also, it has been widely agreed that people spend more time on a task (Lepper, 1988) and put more effort into it if they have stronger intrinsic motivation for it. Therefore, the number of sections students completed, the time spent on the learning task, and the scores of the post-questionnaire were taken into consideration as three different measures of students' intrinsic motivation.

1. Animation and intrinsic motivation

When comparing the two versions of the CBI lessons (animation or no-animation) for intrinsic motivation, the statistics procedure of analysis of covariance (ANCOVA) was used to analyze the data. The number of sections students completed, the time spent on the learning task, and the scores of the post-questionnaire were three separate dependent variables in three ANCOVA. The independent variable was the lesson version—animation or no-animation. The covariate variable was the attitude toward mathematics, which was measured by the last question in the pre-questionnaire. It was found that, on the measure of intrinsic motivation in the post-questionnaire, subjects who received animation scored lower than subjects who received no animation (high points refer to less motivation), F(1,44) = 3.11, p = .084. That is, in this study, subjects who received animation had stronger intrinsic motivation on CBI than those who received no-animation.

For each of the other two dependent variables, time spent on the learning task and sections completed by the students, no statistically significant differences were detected between the animation group and the no-animation group.

2. TV-viewing behavior and intrinsic motivation

The question to be analyzed was when or under what conditions TV viewing behavior would, regardless of animation, increase learners' intrinsic motivation in CBI. For each of the six behaviors, an analysis of variance (ANOVA) for simple linear regression was used to analyze the data. The total score on the post-questionnaire was used as the dependent variable for the measure of intrinsic motivation and each of the six different purposes of TV viewing behavior was used as the independent variable respectively for these analyses. One major result was that students who rated "to learn" as more important for their purpose of TV viewing had moderately higher intrinsic motivation, F(1, 45) = 3.8, p=.057. Other purposes for viewing TV did not make statistically significant differences in intrinsic motivation toward learning from CBI. Table 1 presents the F-values and p-values for the effects of each TV viewing behavior on intrinsic motivation toward learning from CBI.

Table 1. F Values and p Values for the Effects of Each TV Viewing Motive on Intrinsic Motivation toward CBI

TV Viewing Motive	F (1, 45)	p-value
To Pass Time	.14	.707
To Learn	3.8	.057
For Companionship	.16	.694
To Forget	.26	.113
For Arousal	.05	.825
For Relaxation	.47	.496

From Table 1, the major result was that students who rated "to learn" as more important for their purpose of TV viewing had moderately higher intrinsic motivation as measured by the post-questionnaire, F(1, 45) = 3.8, p = .057. This result was predictable because students who watched television for the purpose of learning something perhaps had a positive attitude towards learning in any environment. The purpose of "to forget", which may be statistically significant in intrinsic motivation toward learning from CBI is for further investigation. Other purposes for viewing TV did not make significant differences in intrinsic motivation toward learning from CBI.

3. TV viewing behavior or TV viewing time and the effects of animation on intrinsic motivation

ANOVA for multiple linear regression was used to analyze the influence of TV viewing behavior or TV viewing time on the effects of animation on

Table 2. P-values for the Influence of TV Viewing Time or Purposes on the Effects of Animation on Intrinsic Motivation

	Post-questionnaire	Time on the Task	Sections Completed
Watching TV Time	.718	.258	.278
To Pass Time	.679	.453	.758
To Learn	.858	.880	.593
For Companionship	.274	.237	.458
To Forget	.700	.843	.633
For Arousal	.640	.383	.216
For Relaxation	.243	.104	.292

intrinsic motivation toward CBI. For each ANOVA, the type of lessons and the rank of each TV viewing purpose, or TV viewing time, were two independent variables. The number of sections students completed, the time spent on the learning task, and the scores on the post-questionnaire were separate dependent variables in each ANOVA.

The results of daily TV viewing hours before the 12th grade ranged between 2.5 and 4, which was consistent with other studies. However, there was no significant interaction between TV viewing time or TV viewing behavior and the effects of animation on intrinsic motivation. Table 2 gives the p-values.

4. *TV viewing time or TV viewing behavior and achievement*

This was done by letting CBI lesson scores be the dependent variable and the six different purposes of TV viewing behavior as well as the hours spent watching TV be the independent variables in order to build a multiple linear regression for the analyses. Students who watched TV more before they entered college had worse performance on this CBI lesson than those who watched TV less, (correlation coefficient r = -.308, p = .029). Students who ranked "for arousal" more important performed worse than those who ranked "for arousal" less important, correlation coefficient r = .262, p = .053.

Table 3. Correlation Coefficient of Achievement Performance and Each of the Factors Listed in the Left Column

	r	p-value
Watching TV Time	-.308	.029
To Pass Time	.044	.864
To Learn	-.204	.119
For Companionship	-.199	.176
To Forget	.093	.533
For Arousal	.262	.053
For Relaxation	-.106	.590

IV. Discussion and Conclusion

The present investigation examined the effects of TV viewing behavior and animation on intrinsic motivation toward learning from CBI. The findings offer several significant contributions to the study of intrinsic motivation.

In this study, students who majored in the mathematics department of the school of education did more sections, F(1, 45) = 5.81, p = .02 and spent more time on the learning material, F(1, 45) = 10.29, p = .002, than students majoring in educational computing. One possible reason for this fact was that students majoring in the mathematics department might have been more interested in the learning material than those majoring in educational computing because the learning material was more related to their academic work. This result was consistent with the results of many other studies which contend that lesson content and learner background are important factors in determining intrinsic motivation toward learning from CBI.

It was expected that animation would yield more positive results on intrinsic motivation than non-animation for all three measures of intrinsic motivation: time on task, sections completed, and post-questionnaire. That is, the group with animated graphics was expected to complete more sections, spend more time on the learning task, and have lower post-questionnaire scores. When the level of preference of mathematics was used as a covariate variable, however, the results of the statistics of ANCOVA did not support the first two expectations .

More than 65 percent of the learners did not have any computer learning experience. Therefore, the CBI lesson approach was new to them. These subjects were volunteers who knew that their achievement performance did not relate to their grades or earn them extra credit. These students could be classified as information processors. For this kind of learner, new and different approaches generate considerable intrinsic motivation (Newby, 1989). Therefore, the program provided a baseline of intrinsic motivation for both the animation group and the non-animation group.

Nevertheless, the group with animation scored significantly lower on the post-questionnaire than the group without animation, F(1,45) = 3.10, p = .085. (A higher value on the post-questionnaire indicates a lower level of motivation.) This questionnaire value indicates that animation produces a strong intrinsic motivation. Because new approaches to instruction generate some intrinsic motivation as mentioned above, one might raise the question "Would the effects of animation on intrinsic motivation be larger if the effects of new and different approaches were reduced." Further studies might address this point.

The results of students' TV viewing purposes showed that the preference from the most to the least is (1) for relaxation; (2) to pass time; (3) to learn; (4) for companionship; (5) for arousal; and (6) to forget. Among these six purposes, only "for arousal" and "to forget" did not have significant differences; the rest of the purposes were significantly different using pairwise comparison, $Z > 1.6$, $p < .06$. These findings extend the results of other research which found that high school students tended to watch TV more for relaxation than did students in lower grades. The present study has found that relaxation was the most important reason for college students to watch TV.

Students who watched TV more before they entered college had worse performance on the CBI lesson than those who watched less, $r = -.308$, $p = .029$. Students whose TV viewing behavior was "for arousal" performed worse than those who did not give "for arousal" a high ranking, $r = .262$, $p = .053$. As other studies have suggested, this might be due to the fact that elementary and high school students who watched more TV for arousal devoted less time to their studies, which resulted in weaker academic background. In fact, in this study, TV viewing time and the TV viewing purpose "for arousal" have moderately high correlation, $r = -.415$.

One interesting finding is that students who watched MTV more performed better than students who watched MTV less, F(1,44) = 1.25, p = .216. However, it is not statistically significant. This result is opposite to the result of TV viewing time. Finally, further research on correlation between watching MTV behavior and intrinsic motivation toward learning from CBI were needed. It is hypothesized that a positive correlation will be found.

For this particular concept, the Venn diagram, and the particular subjects in this study, the following conclusions, with respect to the hypotheses addressed, can be stated:

C1 Subjects' intrinsic motivation was moderately higher if the graphics of CBI lessons were animated.

C2 Subjects' intrinsic motivation was moderately higher if their major TV viewing purpose was "To learn".

C3 TV viewing behavior did not influence the effects of animation on intrinsic motivation.

C4 TV viewing time did not influence the effects of animation on intrinsic motivation.

C5 The higher the ranking for "arousal", the lower the academic achievement.

C6 The more the time spent on watching TV, the lower the academic achievement.

It was suggested that broader concepts in mathematics, larger populations, and larger numbers of samples should be considered in further studies.

Appendix

Pre-Questionnaire

1. How many hours per day did you spend watching TV?
   In 1st-6th grade? ________ hours
   In 7th-9th grade? ________ hours
   In 10th-12th grade? ________ hours

2. Please mark the following 6 items from the most to the least preference, using 1-6 respectively, for reasons why you watched TV.
   ____ To pass time
   ____ To learn
   ____ For companionship
   ____ To forget
   ____ For arousal
   ____ For relaxation
3. How many hours per day did you spend watching M.T.V. now?
   ____ hours

4. Have you learned any materials from Computer-Based instruction (CBI)?
   A. Yes B. No (If No, skip No. 5)

5. You think learning from CBI is effective.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

6. You like mathematics most of the time.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

Post-Questionnaire

1. I had had instruction about Venn diagrams be-fore I started this computer program.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

2. I feel that computers are helpful in learning mathematics.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

3. I like to use computers to learn mathematics.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

4. I would like to learn Venn diagrams in this approach if I need to learn them again.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

5. I would like to return to this program.
   A. Strongly Agree B. Agree C. Undecided
   D. Disagree E. Strongly Disagree

References

Bates, A. W. (1983). Adult learning from education television: The open university. In Michael A. J. Howel (ed.), *Learning from television: Psychological and educational research.* New York: Academic, 57-77

Becker, H. J., & Sterling, C. W. (1987). Equity in school computer use: National data and neglected consideration. *Journal of Educational Research, 16*, 11-16.

Chu, G. C., & Schramm, W. (1967). *Learning from television: What the research says.* Washington, D. C.: National Association of Educational Broadcasters.

Clark, R. E. (1985). Evidence for confounding in computer-based instruction strategies: Analyzing the meta-analyses. *Educational Communication and Technology Journal, 33*(4), 249-262.

Criwwell, E. L. (1989). *The design of computer-based instruction.* New York: Macmillan.

King, W. A. (1975). A comparison of three combinations of text and graphics for concept learning (Report No. NPRDC-TR-76-16). San Diego, CA: Navy Personnel Research and Development Center. (ERIC Document Reproduction Service No. ED 112 936)

Kodaira, S. I. (1986). Television for children in Japan: Trends and studies. (ERIC Document Reproduction Service No. ED 275 313)

Kozma R. B. (1991). Learning with media. *Review of Educational Research, 61*(2), 179-211.

Lepper, M. R., & Gurtner, J (1989). Children and computers: Approaching the Twenty-First Century. *American Psychologist, 44*, 170-78.

Lepper, M. R. (1988). Motivational considerations in the study of instruction. *Cognition and Instruction, 5*(4), 289-309

Lyle, J. (1972). *Television in daily life: Patterns of use overview.* In E. A. Rubbinstein, G. A. Comstock, & J. P. Murray (eds.), Television and social behavior, Rockville: The National Institute of Mental Health, 1-32.

Moore, M. V., Nawrocki, L., & Simutis, Z. (1979). *The instructional effectiveness of three levels of graphics displays for computer-assisted instruction* (Report No. ARI-TP-359). Arlington, VA: Army Research Institute for the Behavioral and Social Sciences. (ERIC Document Service No. ED 178 057)

Montgomery, D. C. (1991). *Design and analysis of experiments.* New York: John Wiley & Sons.

Newby, T. J. (1989). Increasing intrinsic motivational change within organizations. *Performance & Instruction, 28*(6), 36-41.

Reed, S. K. (1985). Effect of computer graphics on improving estimates to algebra word problems. *Journal of Educational Psychology*, 77(3), 285-298.

Rieber, L. R. (1989). A review of animation research in com-puter-based instruction. *Proceedings of the 1989 Annual Convention of the Association for Educational Communications and Technology.*

Rieber, L. R. (1990). Effects of animated visuals on incidental learning and motivation. *Proceedings of the Convention of the Association for Educational Communications and Technology*, 479-488. (ERIC Document Service No. ED 323 943)

Rieber, L., Boyce, M., & Assad, C. (1990). The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction, 17*(2), 46-52.

Ringness, T. A. (1965). Affective difference between successful and non-successful bright ninth-grade boys. *Personnel and Guidance Journal, 43*, 600-606.

Rubin, A. M. (1977). Television usage, attitudes and viewing behaviors of children and adolescents. *Journal of Broadcasting, 21*, 355-369.

Singer, D. J., & Singer, J. L. (1983). Learning how to be intelligent consumers of television. In Michael A. J. Howe ed., *Learning from television: Psychological and educational research.* New York: Academic, 203-222.

Snow, R. E. (1986). Individual differences and design of educational programs. *American Psychologist, 41*, 1029-1039.

Ugurogulu, M., & Walberg, H. J. (1979). Motivation and achievement: A quantitative synthesis. *American Educational Research Journal, 16*, 375-389.

Winer, B. J., Brown, D. R., & Michels, K. M. (1991). *Statistical principles in experimental design.* New York: McGraw-Hill.

電腦化教學採用動畫與學生「觀看電視的行為」對學生學習動機的影響之探討

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摘　要

本研究嘗試探討電腦教學 (Computer-Based Instruction CBI) 採用動畫與學生「觀看電視的行爲」對學生學習動機的影響。本研究對「觀看電視的行爲」之定義乃是根據 Rubin 教授所定義的「觀看電視行爲」的種類，稍作修改後而得。樣本爲 47 位 Purdue 大學教育學院的大學生。本研究的一些重要的結論包括：(1) 電腦化教學中採用動畫的樣本學生較不採用動畫的樣本學生，學習動機較高；(2)「觀看電視行爲」爲「學習」者，其學習動機較高；(3)「觀看電視行爲」爲「求刺激」者，其學習成果較低；(4) 樣本學生大學以前觀看電視的時間較長者，在電腦化教學中學習成果較低。

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A Study of Conceptual Aspects of Reflection Symmetry

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ABSTRACT

This study was to examine the development of first and second graders' concepts of line symmetry. 511 first graders and 507 second graders, chosen from elementary schools in the central part of Taiwan, Republic of China, took a paper-and-pencil test. After their responses were examined, 56 students from each grade were individually interviewed in order to further investigate their thinking and concepts of line symmetry. By use of processes adopted in the CSMS association in the United Kingdom, the study demonstrated the developmental levels of the low graders' concepts of line symmetry.

Key words: reflection symmetry, conceptual development

I. Introduction

As seen everywhere, symmetrical objects and drawings are important in mathematics courses. Conception of them is involved in recognizing shape, size, location, and direction. Based on the methodologies used in *The Concepts in Secondary Mathematics and Science* (Hart *et al.*, 1981) and *The Study of Junior Middle School Students' Conceptual Development in Reflection, Rotation, and Placement* (Lin, 1987), this study was to analyze the mathematical concepts of line symmetry which are used both in daily life and in the elementary school mathematics curriculum. Paper-and-pencil tests were conducted among first and second graders in order to investigate the development of their concepts of line symmetry. The tests included distinguishing symmetrical pictures, assembling symmmetrical pictures, searching for symmetrical pictures, distinguishing mirror images and partially drawing symmetrical pictures. The interviews were then followed up. Through the tests and interviews, we obtained data about how the students comprehended line symmetry. Then, based on the data, the first and second graders' conceptual development levels in line symmetry were formed.

II. Methods

The initial paper-and-pencil tests were conducted among 224 first graders and 245 second graders in elementary schools from cities, villages, and remote areas. By stratified random sampling of the elementary schools for cities, villages, and remote districts of the supervising areas (Taichung city, Taichung county, Changhua county, and Nantou county), we established the ratio of schools of city: village: remote area as 2:2:2. We also randomized one class in the first and second grade from every selected school. The test was to examine students' reflection on the difficulty of questions and to detect the questions' flaws. Later, the improved and restructured second paper-and-pencil test was given to 511 first graders and 507 second graders (see Appendix A and B). The same sampling method was used to select samples from schools of the same districts, excluding initial written-test sample schools. The ratio of the schools of city: village: remote area was established as 4:7:3. Based on the test results, the features of students' responses on the test were then analyzed. According to their different responses, four tested students from each class were chosen to attend individual interviews. The purpose of the interview was to verify the paper-and-pencil test results and observe the students' thinking. The questions used in the interviews were partially adopted from the paper-and-pencil tests in order to examine the ways students comprehended questions as well as their reasons for making mistakes. Part of the tests were redesigned and restructured experiments which asked students to place, bend, and surround the objects. A mirror, a paper board , a cork board, some rubber bands and small objects were used as the materials of the experiments. For example, a child was asked to surround the symmetrical figure with some rubber bands on the cork board. Data about students' thinking and comprehending the questions by observation and operation were collected. Based on CSMS procedures, the collected data were then classified into four levels of students' conceptual development.

III. Results

1. Findings from paper-and-pencil tests and interviews

The initial test of 224 first graders and 245 second graders indicated that students were able to do a good job on the distinction of shape, distance between the line and two drawings, a drawing symmetrized by a line, features of a symmetrically folded picture, etc. (see Table 1) The result also indicated that the interviewed students were almost able to comprehend the preconcept of symmetry.

After the initial test, it was modified and improved. Another 511 first graders and 507 second graders were tested to see their concepts of line symmetries (see the passing percentage on Table 2). Four students from each class were chosen for individual interviews. The findings were:

(1) The distinction of the drawing which could be symmetrized

Most of students were able to tell whether a drawing could be symmetrized or not (see Table 2. I.). Some students would consider the characteristics of the material while they were distinguishing an object. For example: "the bowl is made of glass," "it is hard;" "the saw is made of iron." Because of the different materials used for a saw, a saw could not be split into two parts. Students got the lowest percentage of passing on the item in this part (see Table 2. I. 5). Students discriminated the object not only from its shape but also from the material's features. Furthermore, students were used to observing a symmetrical drawing or object from a certain direction such as vertically or horizontally. They seldom considered the object from different directions or the direction opposite to the observer. For example, if an isosceles triangle was not put vertically, the opposite side of the triangle was asymmetrical. This example demonstrated that students recognized the symmetrical drawings by using their intuition. They were not able to recognize symmetrical drawing from different directions and angles or by rotating, changing or reversing the location of an object.

(2) Assembling the symmetrical picture

The result reflected that there are large differences of difficulty among test-items in this part of the test. The reasons might be: (i) the direction of axis symmetry--more students could answer correctly when symmetrical drawings were put on a vertical symmetrical axis than on a horizontal one (see Table 2. II. a. 1,3 & II. b. 1,3,4). The percentage of students that were able to correctly recognize sloped-axis symmetry was lower than that horizontal and vertical symmetries (see Table 2. II.a.1,3,4 & II.b.1,2,3). The result falls in line with Fitts *et al.*'s findings in 1956 (Genkin, 1975); (ii) whether the drawing had vertical and horizontal symmetry or not---if the picture was only horizontal, the percentage answering correctly was high (see Table 2. II. a. 3, 5 & II. b. 4); (iii) the complexity of the drawing---the simpler the drawing was, the more correct answers appeared; vice versa (see Table 2. II. a. 3, 5 & II. b. 1,3,5). These phenomena demonstrated that student recognition of the symmetrical drawing was not well developed.

(3) The distinction of bilaterally symmetrical portions

Students' answers to this part of the test were better than those aforementioned (see Table 2. III. a,b,c). Their reflection characteristics on the test were also similar to the aforementioned portions of the test. It was found that when the students observed symmetrical portions, they only looked at the partial picture, and disregarded the whole picture.

(4) Mirror-image phenomenon

In this part of the experiment it was found that the distinction of a picture was closely related to the complexity of the picture's context. It was easier to discriminate the mirror images of the single unit or the assembled picture than to discriminate the mirror images of the double or separated objects. It was difficult for the students to distinguish the distance and the direction (see Table 2. IV. a, b and Appendix B. IV.). The characteristics of the students were : (i) they would distinguish the object and the mirror-image in the same direction (see Fig. 1. a.); (ii) they would move the object in the same direction if it was put on

Table 1. Percentage Passing the Paper-and-Pencil Test on Preconcept of Symmetry

(Test Items See Appendix A)

No.	Item	No. of Problem	Difficulty (%)		
			1st Grade (N=224)	2nd Grade (N=245)	Total (N=469)
I.a.	Distinguish the shapes (Identify whether picture of two objects are same/different)	1	83	83	83
		2	95	97	96
		3	92	96	94
		4	93	97	95
		5	83	86	85
I.b.	Circle the differences between two drawings	1	90	92	91
		2	90	95	93
		3	87	90	89
		4	88	93	91
		5	89	91	90
I.c.	Choose the same shape	1	83	87	85
		2	94	97	96
		3	83	90	87
		4	91	93	92
		5	88	93	91
I.d.	Choose the same two shapes among the following	1	88	91	90
		2	86	88	87
		3	87	91	89
		4	86	90	88
		5	74	82	78
II.a	Identify the distance between the line and two drawings	1	88	89	89
		2	92	92	92
		3	89	94	92
		4	92	91	92
		5	90	91	91
		6	92	93	93
		7	90	94	92
		8	93	93	93
II.b.	Choose the picture which indicates equal distance between the line and two drawings	1	95	97	96
		2	94	97	96
		3	95	96	96
		4	96	97	97
		5	95	97	96
III.a.	Choose the drawing symmetrized by a line	1	82	91	87
		2	89	95	92
		3	86	94	90
		4	72	88	80
		5	83	89	86
III.b.	Distinguish the drawing symmetrized by a line	1	88	94	91
		2	81	79	80
		3	90	94	92
		4	72	75	74
		5	83	88	86
IV.a.	Choose the symmetrically folded part by its unfolded figure	1	77	86	82
		2	80	84	82
		3	75	82	79
		4	80	88	84
		5	81	85	83
IV.b.	Choose the unfolded figure by its symmetrically folded part	1	96	97	97
		2	94	98	96
		3	78	88	83
		4	76	75	76
		5	85	94	90

Table 2. Percentage Passing the Paper-and-Pencil Test on Concept of Symmetry

(Test Items See Appendix B)

No.	Item	No. of Problem	Difficulty (%)		
			1st Grade (N=511)	2nd Grade (N=507)	Total (N=1018)
I.	Choose the drawing which could be symmetrized	1	90	91	91
		2	89	92	91
		3	71	69	70
		4	82	86	84
		5	54	57	56
II.a.	Choose two drawings which can assemble the symmetrical picture (the whole of the picture is illustrated)	1	70	88	79
		2	61	75	68
		3	67	73	70
		4	51	58	55
		5	41	52	47
II.b.	Choose two drawings which can assemble the symmetrical picture	1	75	81	78
		2	62	73	68
		3	82	81	82
		4	57	62	60
		5	39	37	38
III.a.	Choose the bilaterally symmetrical area.	1	78	90	84
		2	76	87	82
		3	68	83	76
		4	71	80	76
		5	73	85	79
III.b.	Choose the bilaterally symmetrical line segment	1	73	86	80
		2	73	84	79
		3	62	64	63
		4	66	80	73
		5	64	76	70
III.c.	Choose the bilaterally symmetrical point	1	82	94	88
		2	58	60	59
		3	63	75	69
		4	76	87	82
		5	65	82	74
IV.a.	Identify the mirror-image	1	79	94	87
		2	80	94	87
		3	86	93	90
		4	78	94	86
		5	49	73	61
IV.b.	Choose the mirror-image	1	61	91	76
		2	48	73	61
		3	47	77	62
		4	54	80	67
		5	52	79	66
V.a.	Draw the missing part in the symmetrical area	1	69	84	77
		2	82	91	87
		3	66	87	77
		4	14	28	21
		5	6	16	11
V.b.	Draw the symmetrical area on the other side of the axis	1	18	52	35
		2	13	29	21
		3	21	56	39
		4	3	8	6
		5	5	19	12
		6	18	45	32

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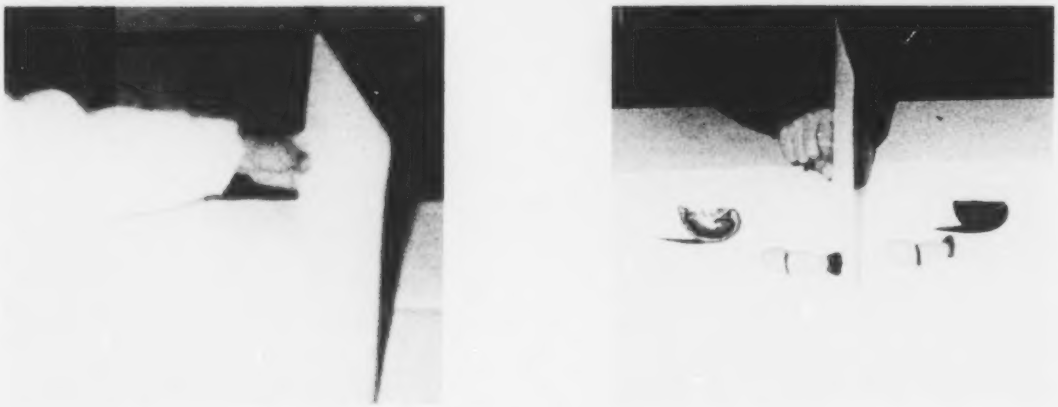
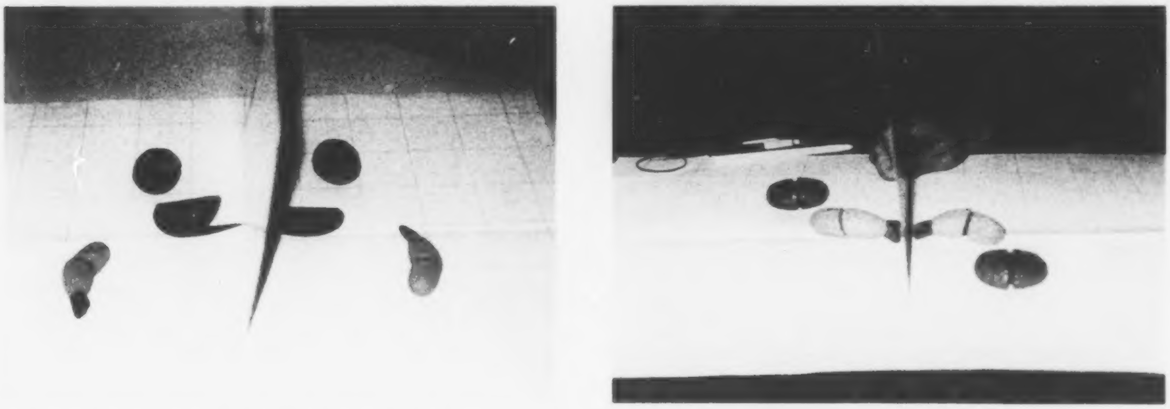


a. Distinguished the object and the mirror-image in the same direction

b. Moved the object in the same direction if it was put on either left or right side



c. Moved the object in the opposite direction if it was put either up or upside down

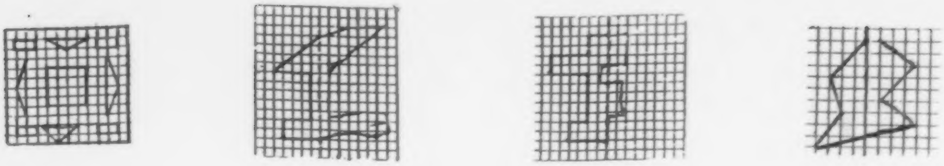
d. Made mistakes both in location and direction

Fig. 1. Types of children's mistakes in constructing the mirror-image.

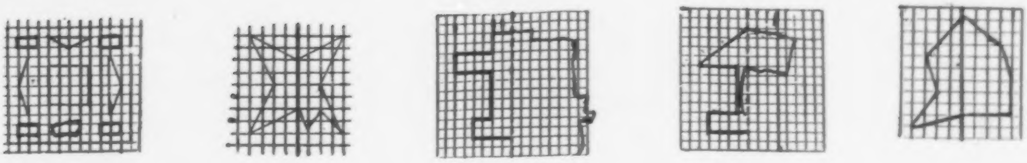
either the left or right side (i.e. movement in plane) (see Fig. 1. b.); (iii) they would move the object toward the opposite direction whether it was put up or upside down (see Fig. 1. c.); (iv) large mistakes in location (see Fig. 1. d.). These phenomena mostly appeared among the first graders; the second graders learning ability was perhaps better than that of the first graders. Furthermore, the second graders already had studied the subject of mirror-images. According to a study of the kindergartners and the second graders by Genkins (1975), kindergartners were unable to distinguish the mirror-image phenomenon but second graders were able to do so. This study indicated that the first graders had difficulties in distinguishing mirror-image. However, it partially supported Genkins' findings that the second graders were able to distinguish mirror-images.

(5) Drawing and surrounding the symmetrical pictures

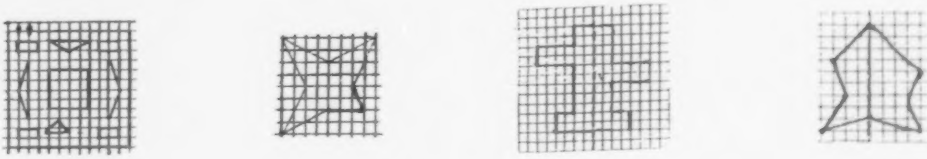
Few difficulties were found for most of the students when they were asked to draw symmetrical points or lines which were parallel or a vertical axis. However, most students could not draw slope correctly (see Table 2. V. a.). Most students were not able



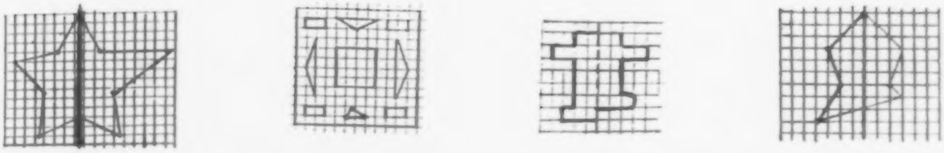
a. Wrong directions



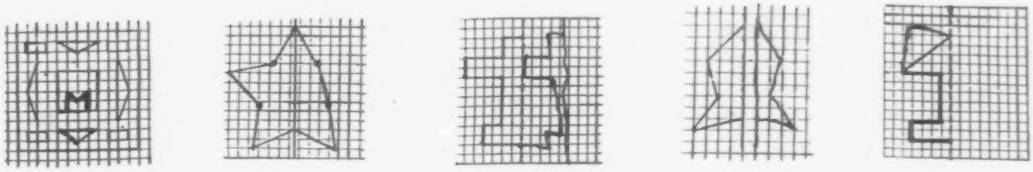
b. Wrong shapes



c. Wrong location



d. The length was wrong



e. Misinterpreting questions

Fig. 2. Kinds of children's mistakes in drawing or surrounding the part of the symmetrical shape

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to draw or surround the half of the symmetrical pictures. Especially, only a few students could draw vertical or horizontal symmetry which contained slope or sloped axis symmetry (see Table 2. V. b.). The mistake that students made were: (i) wrong directions (see Fig. 2.a.); (ii) the difference between shapes was great (see Fig. 2.b.); (iii) wrong location (see Fig. 2.c.); (iv) the difference between the lengths was great (see Fig. 2.d.); (v) misinterpreting questions (see Fig. 2.e.).

The result revealed that students' ability in drawing a symmetrical picture was not well-developed. They were able to draw a picture with one single feature but they had difficulties in drawing a picture with many features.

The study indicated that the first and second graders' attention was centralized; they had difficulties in figuring out two or more concepts. They were used to thinking about one or two factors regardless of some other relevant factors. The second graders, who had a year more learning experience, showed better learning ability and test results than the first graders.

2. Analysis of students' understanding level

The results from paper-and-pencil tests and interviews indicated that the direction of the axis of symmetry and the complexity of the drawings was related to students' response to test items on symmetrical concepts. In this study, we used the method previously used in the research in *Children's Understanding of Mathematics*: 11-16 of CSMS (Hart, 1981). Based on the direction of the axis of symmetry, the drawing complexity, and the homogeneity coefficient between questions, the test questions were first classified into four groups. The results are listed in table 3. The groups of items obtained by the above method were of different difficulties and could be said to require different 'levels of understanding'. The level of understanding displayed by a child in the axis symmetry could then be asessed by determining the most difficult group of items on which the child showed competency. To do this we used a criterion of correctly answering two-thirds of the items within a group. This criterion was also used in the research of into *Children's Understanding of Mathematics*: 11-16 of CSMS. Table 4 shows the pass percentage on each level at each grade level. Table 3 indicates that "visual distinction" questions were associated at Level I and Level II, whereas "drawing problems" were as-sociated at Level III and Level IV. By observing the items included at each level we found some common features of the test items and the students' level of competence and incompetence as follows:

Table 3. Range of Test Difficulty and Response Level of the Paper-and-Pencil Test Taken by the First and Second Graders

Level	Range	No.of Test Item	Total
I	76%~91%	I-1, I-2, I-4, II-a-1, II-b-1, II-b-3, III-a-1, III-a-2, III-a-3, III-a-4, III-a-5, III-b-1, III-b-2, III-c-1, III-c-4, IV-a-1, IV-a-2, IV-a-3, IV-a-4, IV-b-1, V-a-1, V-a-2, V-a-3.	23
II	55%~74%	I-3, I-5, II-a-2, II-a-3, II-a-4, II-b-2, II-b-4, III-b-3, III-b-4, III-b-5, III-c-2, III-c-3, III-c-5, IV-a-5, IV-b-2, IV-b-3, IV-b-4, IV-b-5.	18
III	32%~47%	II-a-5, V-b-1, V-b-3, V-b-6.	4
IV	6%~21%	V-a-4, V-a-5, V-b-2, V-b-4, V-b-5.	5

(1) Level I

A. Features of test items: a) vertical axis; b) pictures of real object, such as a bowl, a cup, etc.; pictures of less complicated geometric shapes, such as line segment, triangle, rectangle, etc.; c) the differences were apparent.

B. Students' competence: a) visual distinction of objects; b) concept of equal distance between symmetrical axis and two objects; c) abilities to distinguish of shape and size were developed.

C. Students' incompetence: a) did not understand the conservation of symmetry; b) used only intuition to observe shapes; c) payed attention to distinct points but unable to observe the whole object; d) could not identify complicated shapes.

(2) Level II

A. Features of test items: a) horizontal or sloped axis; b) picture's structure was more complicated; geometric shapes were not often seen; c) the differences were not very clear; d) they required children to change the direction of observation or rotate the object.

B. Students' competencies: a) able to change the direction for observation; b) able to identify tiny differences among complicated pictures; and, c) able to observe the whole object and image.

Table 4. The Percentage Distribution of the First and Second Graders in Each Comprehension Level

	1st. Grade		2nd. Grade		Total	
Level	One Item	Cumulative Counting	One Item	Cumulative Counting	One Item	Cumulatiave Counting
0	27	100	9	100	19	100
I	35	73	26	91	30	81
II	31	38	28	65	30	51
III	7	7	33	37	19	21
IV	0	0	4	4	2	2

C. Students' incompetence: a) unable to identify compound object mirror -image; b) unable to draw schema of object's image.

(3) Level III

A. Features of test items: a) pictures of abstract, geometric shapes and their differences were not apparent; b) along the sideline on graph paper and draw the half of symmetrical shape.
B. Student's competencies: a) able to draw schema of object's shape; b) able to use space on graph paper as a counting tool, then find out the position of the line segment, point, etc.
C. Students' incompetence: a) unable to draw a symmetrical shape's sideline not parallel or perpendicular to a line on graph paper; b) unable to draw compound object's mirror image.

(4) Level IV

A. Features of test items: a) mirror-image of compound object; b) the sideline of symmetrical shape was not parallel with or perpendicular to the line on graph paper.
B. Students' competencies: a) able to distinguish directions in mirror-image compound object; b) able to draw symmetrical shape's sideline not parallel with or perpendicular to line on graph paper.

In Table 4, we found 73 percent of first graders and 91 percent of second graders achieved Level I, 38 percent of first graders and 65 percent of second graders achieved Level II, 7 percent of first graders and 37 percent of second graders achieved Level III, and only 4 percent of second graders achieved Level IV. The findings indicated that most of the first and second graders' comprehension of axis symmetry level stayed at Level I and Level II. Students' comprehension of axis symmetry was seldom found at level III and Level IV.

IV. Conclusion

The traits which form the concept of line symmetry are shape, distance, direction, and size. According to psychological reports, the traits of a concept are sequentially formed, from concrete to abstract, from simplification to complexity. If the traits of a concept are fewer, it is easier for young children to grasp (Cheng, 1986). Students were able to answer the questions in Level I and II at sight. This was because the questions in Level I and II required fewer conceptual traits to comprehend. Most of the shapes, distances, directions, and sizes in level I and II were with one single trait rather than compound traits. This demonstrated that students were able to comprehend the sole trait.

H. Klausmeier's study in 1974 indicated that conceptual development is in three important phases: recognition, classification, and formation. These phases are developed in sequence. The study suggested that the first and second graders' recognition phase in elementary schools is well developed, but it is still a little difficult for them to distinguish the two halves of a drawing. This revealed that their classification phase is not well developed. The study also revealed that students had difficulties in expressing their symmetrical concepts while being interviewed. It implied that students' formation phase had not started yet.

In summary, the concept traits of a symmetrical picture and the developed concept level are the factors which influence students' answers while they are tested. The fewer or simpler traits which are constituted for a symmetrical picture and the better students' concepts of symmetry are developed; the better the test results are. The study found that there was no problem for the first and second graders to distinguish shape, size, distance, and direction of line symmetry. This finding can be offered as a reference in curriculum design so as to fulfill their fundamental experiences.

When students distinguished the traits of an object, they always associated it with the material which the object is made of, as well as the material's features. In order to be thoroughly understandable, the question and instructions should be very clear, so that students can get the key points.

As these are often seen, symmetrical objects and axis symmetry are vertically or horizontally placed. When the first and second graders are instructed to observe these kinds of objects, they can be guided to observe the objects from different directions.

The first and second graders' visual phase in observing the traits of line symmetry is already developed. Therefore, the visual observation curriculum can be put into practice. Regarding the operating and drawing, it may be hard to get a good learning effect. When students observed reflection, most of them paid attention to outstanding traits. They hardly figured out what the real reflection was when several objects were reflected. Therefore, students should be given more chances to observe reflection during the period of instruction.

Acknowledgment

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References

Cheng, Chao-Chen (1986). *Psychology.* Hongkong Branch: Shang Wu Press Co..

Fitts, P. M. *et al*, (1956). Stimulus correlate of visual pattern reception: A probability approach. *Journal of Experimental Psychology*, *51*, 1-11.

Genkins, E. F. (1975). The concept of bilateral symme try in young children. Rosskoph, M. F. (ed.), *Children's mathematical concepts.* New York: Teachers College, Columbia University, 5-12.

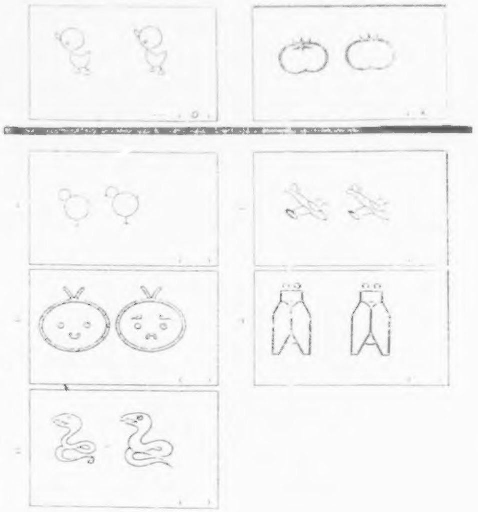
Hart, K. M. (ed.), (1981). *Children's understanding of mathematics.* London: John Murray.

Lin. F. L. (1987). *The study of junior middle school students' development in reflection, rotation, and placement.* National Taiwan Normal University.

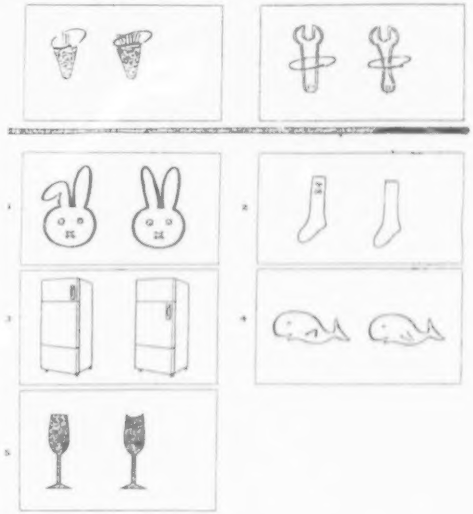
Appendix A. Test Items of the Initial Paper-and-pencil Test on Preconcept of Symmetry

I. Distinction of the shapes

a. Identify whether two objects are the same/different
Example:

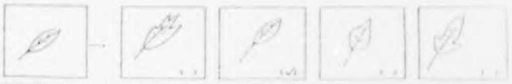


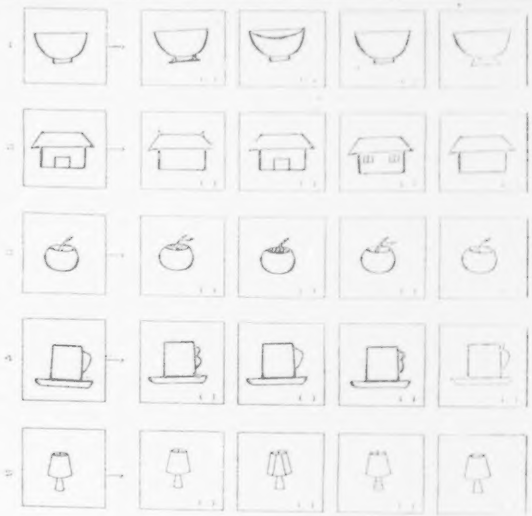
b. Circle the difference between two drawings
Example:



c. Choose the same shape

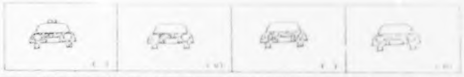
Example:

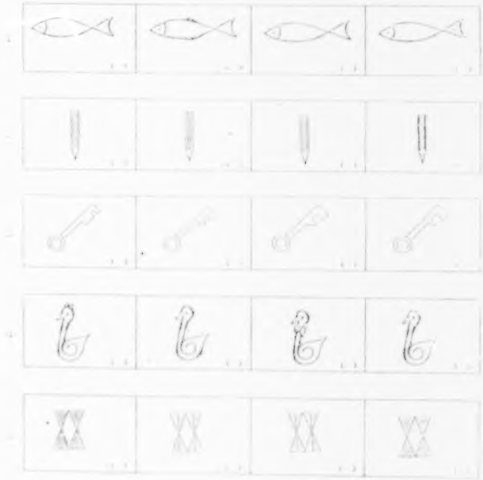




d. Choose the two same shapes among the following

Example:

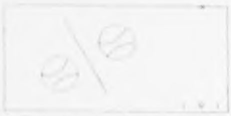




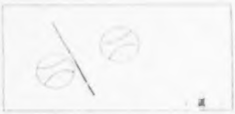
II. Identification of the Distance between the line and two drawings

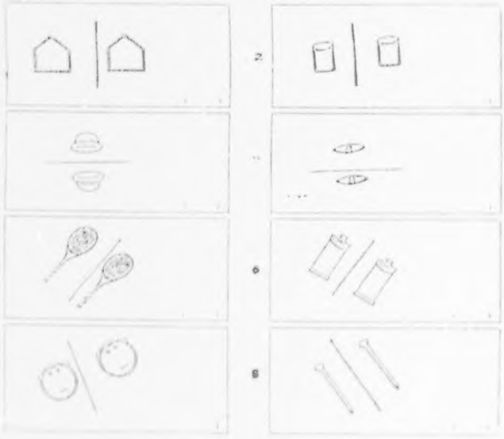
a. Identify the picture which indicates equal distance between the two drawings

Example 1:



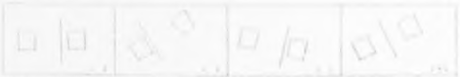
Example 2:

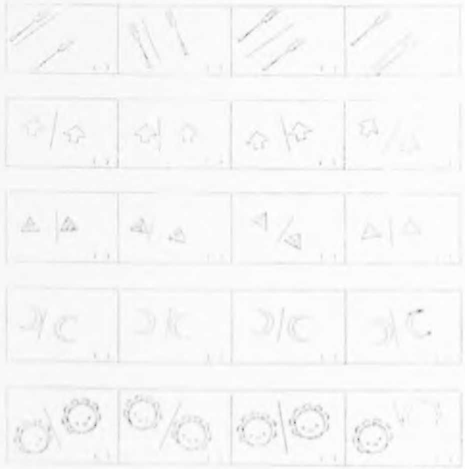




b. Choose the Picture which indicates equal distance between the line and two drawings

Example:

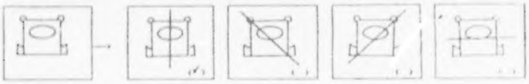




III. Identification of the drawing symmetrized by a line

a. Choose the drawing symmetrized by a line

Example:



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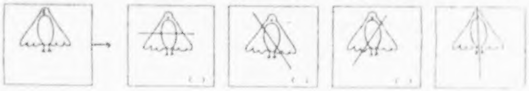

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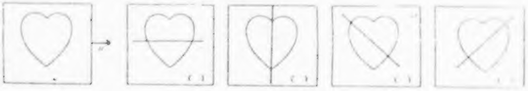

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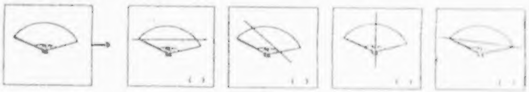

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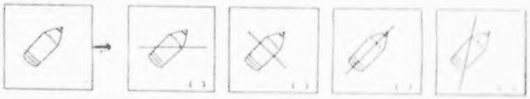

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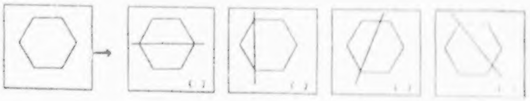
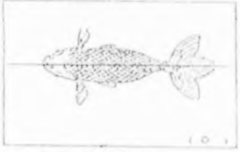


b. Distinguish the drawing symmetrized by a line

Example 1:



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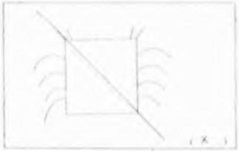

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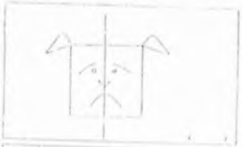

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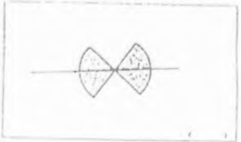

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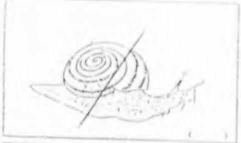

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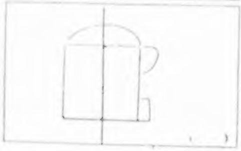

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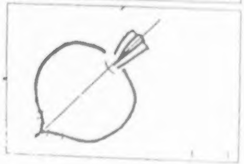
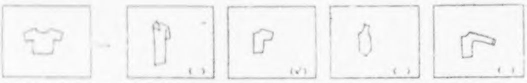


IV. Identification of the features of symmetrically folded pictures

a. Choose the symmetrically folded part by its unfolded figure

Example:



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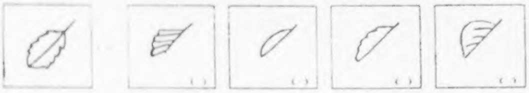

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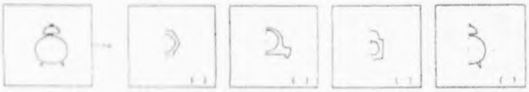

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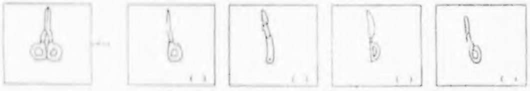

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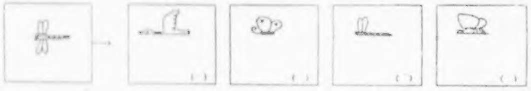

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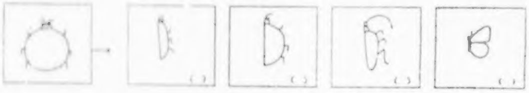
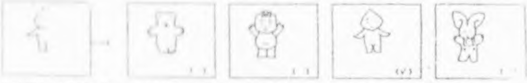


b. Choose the unfolded figure by its symmetrically folded part

Example:



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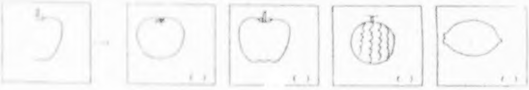

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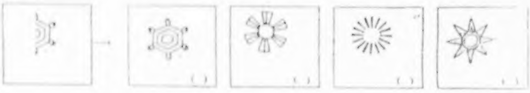

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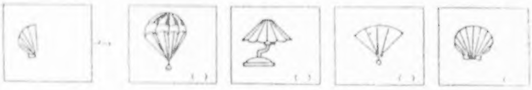

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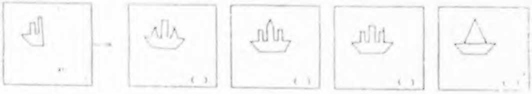

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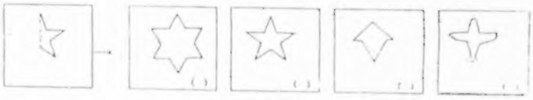
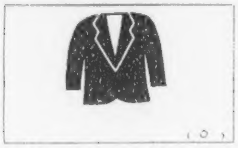


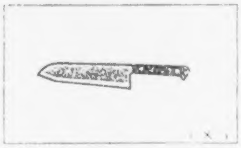
Appendix B. Items of the Written Test on the Concept of Symmetry

I. Choose the drawing which could be symmetrized

Example 1:



Example 2:



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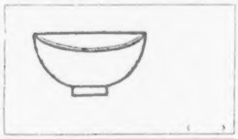

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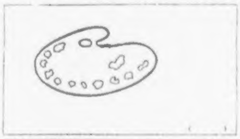

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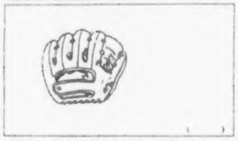

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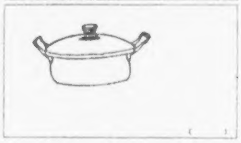

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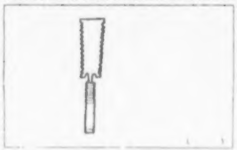
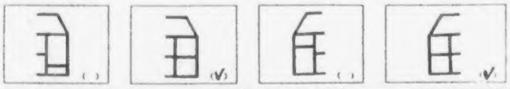


b. Choose two drawings which could be combined to make the symmetrical picture

Example:



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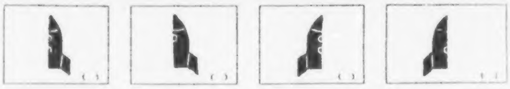

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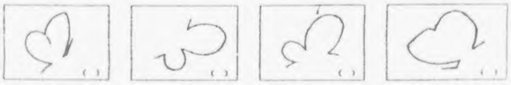

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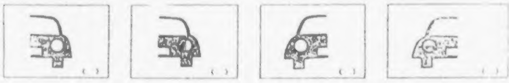

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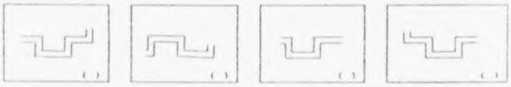

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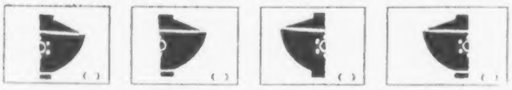
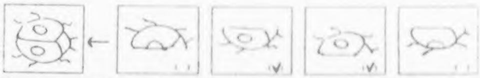


II. Assembling the symmetrical picture

a. Choose two drawings which could be combined to make a symmetrical picture (the whole picture is illustrated)

Example:



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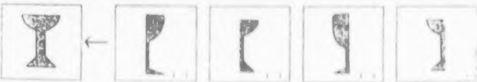

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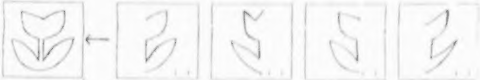

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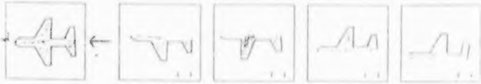

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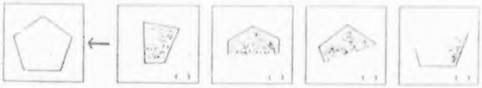

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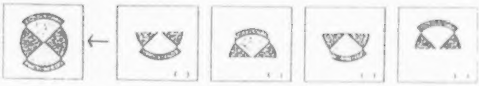
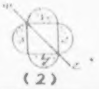


III. Distinction of bilaterally symmetrical portions

a. Choose the area covered by ㄅwhen the figure is folded along the axis 甲乙

Example:



(2)

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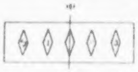

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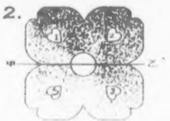

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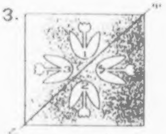

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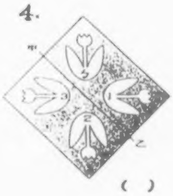

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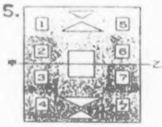

( )

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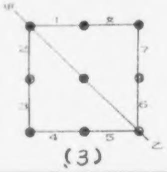
b. Choose the line segment covered by 夂 when the figure is folded along the axis 甲乙

Example:



(3)

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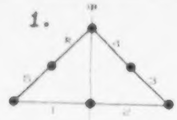
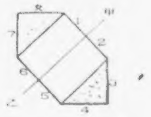


( )

2.



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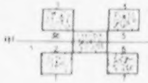

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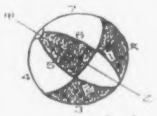

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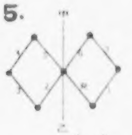

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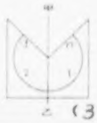
c. Choose the point covered by 冂 when the figure is folded along the axis 甲乙

Example:



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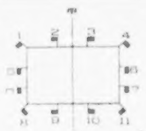

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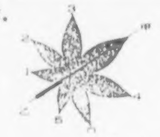

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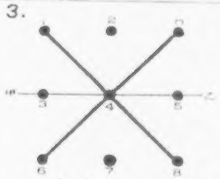

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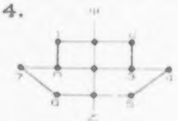

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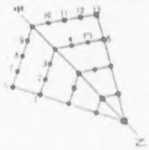

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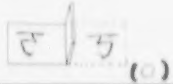
IV. Mirror-image phenomenon

a. Identify the mirror-image

Example 1:



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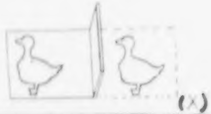
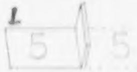
Example 2:



(X)

1.



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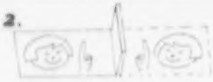

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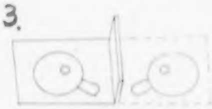

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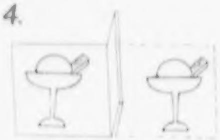

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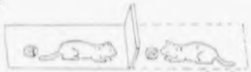

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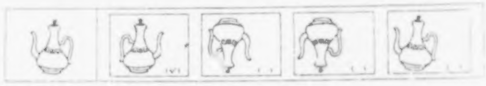
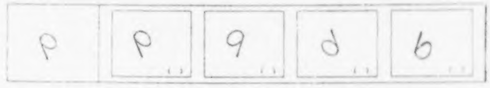
b. Choose the mirror-image

Example:



1



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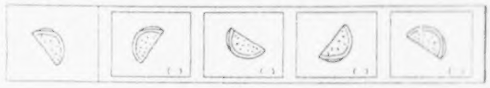

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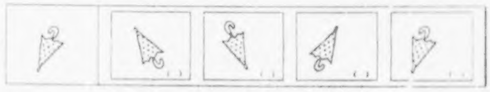

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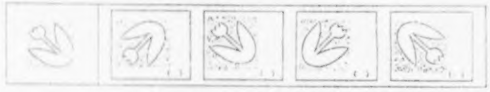

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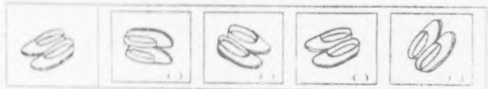
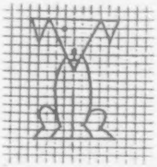


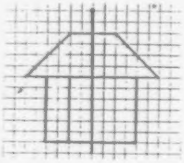
V. Draw some portion of a picture

a. According to the instruction, finish the following pictures.

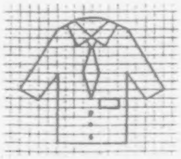
1. Where is the other eye of the dog? Draw it.



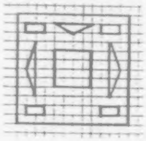
2. This house should be the same on the two sides of the red line. There is something missing. Draw it.



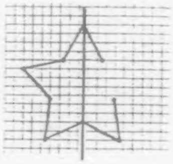
3. There is one pocket on each side of this suit of clothing, where is the correct position of the left side pocket ? Draw it.



4. Both the shapes at the upper and the lower side should be the same. There is something missing. Draw it.

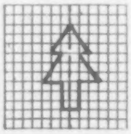


5. A line is across this star. The two parts of the star should be the same. There is someting missing. Draw it.



b. Draw half of the shape.

Example 1:



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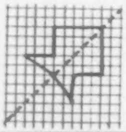

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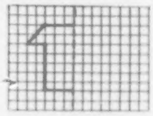

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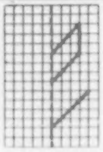

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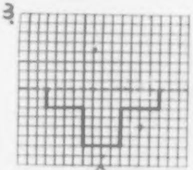

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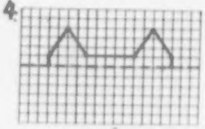

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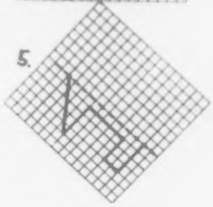

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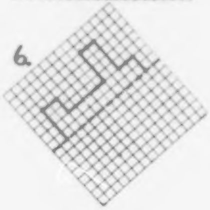

我國國小學童對稱概念的發展研究

劉湘川 • 劉好

國立臺中師範學院數理教育學系

摘　要

本研究之目的乃在探討國小低年級學童對稱概念之發展、了解情況以及差異性，並觀察其對稱概念的思考類型及分析可能之錯誤，藉以提供小學教師教學及課程編訂之參考。就台中師院輔導區（台中市、台中縣、彰化縣、南投縣）內之小學，以城市、鄉村、偏遠學校分類，採分層隨機抽樣方式，選取一年級511位，二年級507位學童施行筆測及一、二年級各56位學童進行個別面談。

研究進行以「質」爲主，以「量」爲輔，經「質」與「量」的觀察中，發現筆測反應較優者，在訪談操作中大部分表現亦較佳。研究結果顯示：二年級學童比一年級學童概念清楚，對稱圖形的辨別中，學童普遍清楚左右對稱現象，上下對稱的特性次之，對稱軸爲傾斜之現象則較不熟悉；在鏡射概念方面，發現學童對鏡映像的前後、左右關係不甚了解，經給予實際鏡子操作後，始較能體會鏡映現象。經由理解層次分析發現，大部分學童落於第一、二層之線對稱概念有關的一些基本特性之理解，及直觀辨別線對稱形狀的特徵。而具備第三、四層次的線對稱特徵之抽象思考與推斷能力者之比例甚低。針對上述研究結果，本研究提出一些建議。

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An Experimental Study of a Teaching Unit of Secondary School Science Developed by the Theories of Constructivism

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ABSTRACT

This research paper seeks to find out :
(1) the effectiveness of a teaching unit which is developed in accord with theories of constructivism;
(2) students' attitude toward teaching strategies associated with the experimental teaching material;
(3) teachers' view of constructivist teaching material.

Six schools of different socio-economic regional backgrround in southern Taiwan were chosen for this experiment. In each of these schools, two classes were chosen for experimentation, one designated as the experimental class, the other as the control class.

This research paper seeks to apply the theories of constructivism, knowledge restructuring and individualized teaching to the design of new teaching material on buoyant force-related knowledge in the junior high school textbook. Six experimental junior high schools were chosen from different regions: an Executive Yuan-dominated city, a Provincial Government-dominated city, a county-dominated city, a coastal area and a mountainous area. All of the areas are in the southern part of Taiwan. Five of the six schools each had two representative science teachers. Two classes were formed from the representative science teachers' classes. One was designated the experimental class; the other the control class. The sixth school, located in the mountainous area, has only one science teacher. Two classes were formed from the representative science teacher's classes. Similarly, one was the experimental class; the other the control class.

The study design was $\frac{XOX}{O\ \ O}$, in which "X" represents use of the new teaching material, and "O" represents data collecting. Four tools of measurement were used in this study:
(1) Pretest-posttest of learning achievement for each chapter.
(2) Questionnaire for students' evaluation of new teaching material.
(3) Science-teachers' perceptions questionnaire (by interview) relating to the problems of science teaching of the experimental group.
(4) Scientific- process ability test for the student.

The results of the study showed that the new teaching material received favorable evaluations among the students. Also, learning achievement with the new materials surpassed that of the old ones. The new teaching material was also welcomed by the science teachers. They appreciated its emphasis on student ability for independent reflection. They also approved of its design, which emphasized both questions applicable to practical life experiences and open-ended discussion, which in turn

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facilitated developing student problem-solving ability and enhanced student learning interest.

Key words: constructivism, knowledge-restructuring, individualized-instruction

I. Introduction

For several decades, science education has been deeply influenced by constructivism and cognitive science. Many science educators, such as Bodner(1986), Cleminson (1990), etc., assert that knowledge cannot be proved, nor can it be tested. They also assert that knowledge is obtained through mankind's construction, not through its discovery (Dusche, 1990; Hodson, 1988; Kuhn, 1970; Pope & Gilbert, 1983; Novak, 1988; Nussbaum, 1989). Cognitive psychology focuses its view of learning on the following:

(1) Knowledge can be obtained only through being assimilated into the individual's cognitive structure. Therefore, knowledge will be rejected within the individual cognitive structure, when it cannot be assimilated and reasoned out (Piaget, 1964, 1974).

(2) Learning is an active, constructional and object-directed process. It is also developed from within outward (Shuell, 1986).

Cognitive psychology also focuses its view of science teaching on the following:

(1) The teaching process ought to agree with constructivism, namely, to assert that teaching should be able to lead students toward self-construction, modification and adjustment (Guo, 1992).

(2) Teaching strategies should apply theories of cognitive psychology and personal construct psychology (Leinhardt & Greeno, 1986; Piaget, 1964, 1974; Pope & Keen, 1981; Reif, 1987; Shuell, 1986)

(3) One of the teaching purposes is to remove student misconceptions and to conduct a concept change or concept restructuring (Duschl, 1990; Hewson & Hewson, 1988; Leinhardt & Greeno, 1986; Posner, Strike, Hewson & Gertzog, 1982; Reif, 1987; Strike & Posner, 1982; Vosniadou & Brewer, 1987).

Several different object-oriented teaching modes have been developed according to the above principles. For example, the three-stage learning cycle which emphasizes eliminating student misconceptions, namely, by discovering a students' alternative structure → causing a contradiction of concepts → guiding the student toward cognitive readjustment (Hsu *et al.*, 1990; Lawson, *et al.*, 1989). Another five-stage learning cycle emphasizes changing students' natural concepts, namely, ensuring a research direction → bringing out student thought → re-constructing student thought → applying the new thought → reviewing the changed thinking pattern (Guo, 1992; Driver & Oldham, 1986).

The Science Curriculum Improvement Study (i.e., SCIS), The Science 5/13 in Britain, and The Australian Science Education Projection in Australia (i.e., ASEP) are the curricula developed using theories of constructivism and cognitive science in the early years. But Driver & Oldham's(1986) is representative of the later science-curriculum improvement using these theories.

The following diagram (Fig.1 and Fig.2) indicates that curriculum design includes both designing the material and the teaching method.

Figures 1 & 2 also show the ideas of a science curriculum developed with cognitive psychology and principles of constructivism. The theory takes into account student misconceptions and tries to clarify them during the process of teaching in terms of an appropriate curriculum design. However, the theory has not taken into account experimental teaching and individual student needs. To amend the theory, therefore, a better design is needed as follows:

1. A flow chart of new teaching material

A teaching mode with each unit constituted by core teaching material and various selected learning material has been developed. The mode takes into consideration students' interests, students' ability, students' experience, students' family backgrounds, and the teaching environment, etc.. Even more, the mode meets the requirements of different thought patterns, learning attitudes and personal willingness. The mode is as follows:

According to the diagram, the core material will teach the fundamental contents that students have to learn and understand. Hence the core material is taught to the whole class. Students who pass the test on the core material will be orientated to selected

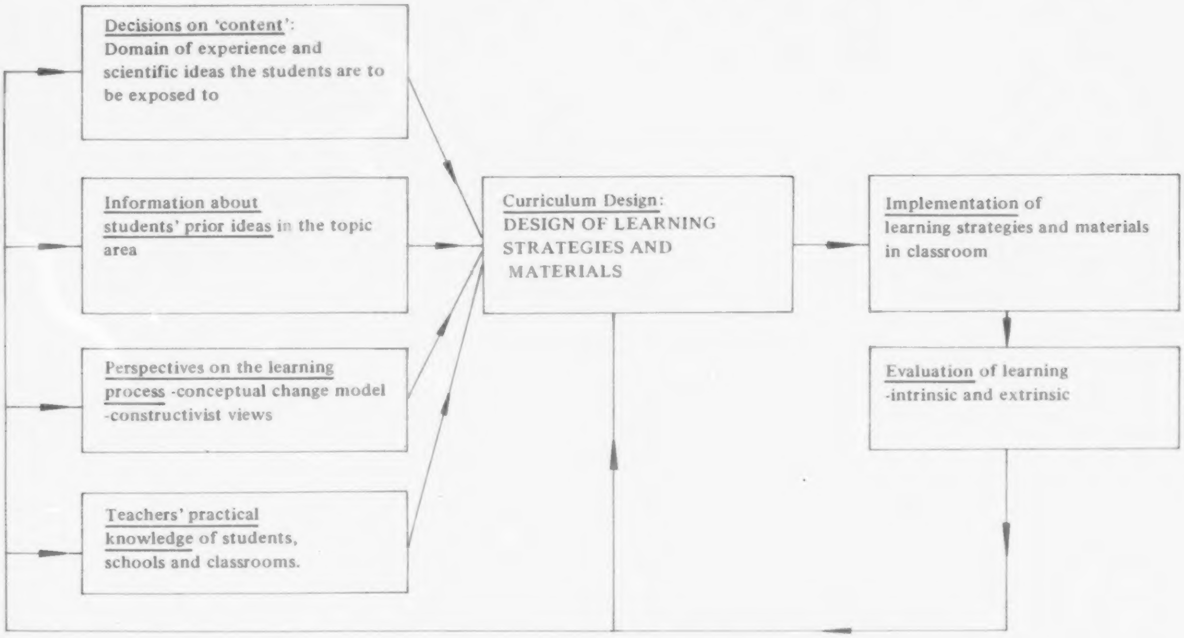
Decisions on 'content':
Domain of experience and scientific ideas the students are to be exposed to
Information about students' prior ideas in the topic area
Perspectives on the learning process -conceptual change model -constructivist views
Teachers' practical knowledge of students, schools and classrooms.
Curriculum Design:
DESIGN OF LEARNING STRATEGIES AND MATERIALS
Implementation of learning strategies and materials in classroom
Evaluation of learning -intrinsic and extrinsic

Fig. 1. Mode of constructivist design of curriculum (from Driver & Oldham, 1986)

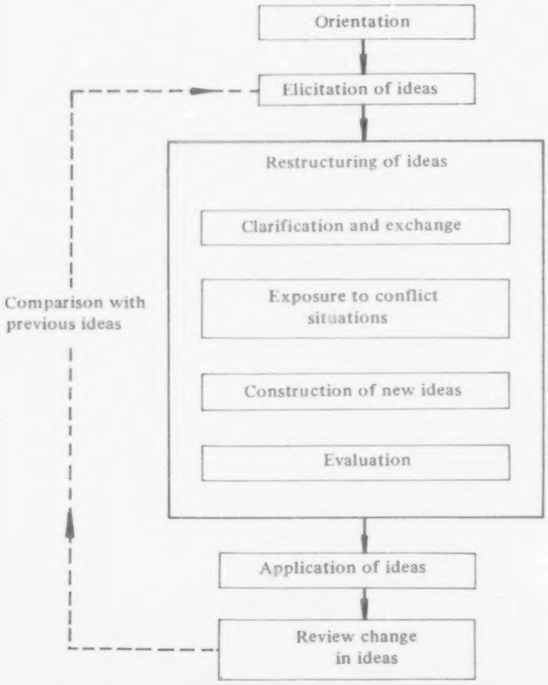
Orientation
Elicitation of ideas
Restructuring of ideas
Clarification and exchange
Exposure to conflict situations
Construction of new ideas
Evaluation
Application of ideas
Review change in ideas
Comparison with previous ideas

Fig. 2. Stages and objectives of science teaching

material either of their own choice or under the teacher's guidance (the teacher provides all equipment for learning activities). One way to judge student learning of the selected material is to give a test on each unit. Therefore, this teaching format will meet the goals of individualized teaching. The symbols C_1, C_2, C_3, T_1, T_2, T_3 and P_1, P_2, P_3, for the selected materials represent the character of each unit. Thus C indicates that the unit of teaching stresses creativity. T indicates the unit of teaching stresses rules and theories. P indicates the application of theories and rules. The subscripts 1, 2, and 3 represent the levels of the teaching material. In general, "1" represents knowledge that is reconstituted by the levels of memory and reasoning. "2" represents knowledge constituted by the levels of reasoning and application. "3" represents knowledge reconstituted by the levels of application and synthesis.

2. Removing misconceptions and applying the theories of concept restructuring for new teaching material

The design of teaching material for each unit is based on the structure of Driver & Oldham's(1986) constructivist design mode. The contents of the new curriculum include force, the pressure of fluid, and

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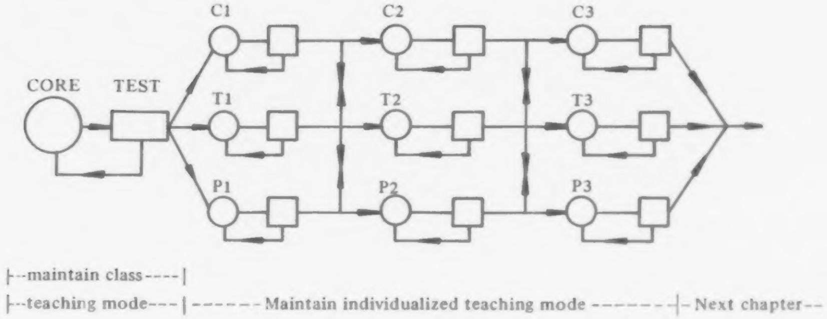
C1
C2
C3
CORE
TEST
T1
T2
T3
P1
P2
P3
|--maintain class----|
|--teaching mode---|------Maintain individualized teaching mode -------|- Next chapter--

Fig. 3. Flow chart of in dividualized instruction

buoyant force from the junior high school textbook. The design of each chapter contains core material and selected material. Students' misconceptions are collected from a research paper called "A diagnostic analysis of the causes of misconceptions about buoyant force for middle school students and remedial strategies (Chiang, 1991)". The theory of concept change is based on Vosniadou & Brewer's theories of knowledge restructuring in development(1987). Teaching materials designed according to the above theories are guided by experimental activities, except for certain high levels of creative and theoretical material. Besides, each unit of material contains reading material, Socratic questions, and self evaluation. Each of the teaching goals and design concepts is explained as follows:

(1) Experiment

Usually, the format of experimental activities includes purpose, prediction and hypothesis, discoveries, and discussion. The teaching purpose of the experiment is to develop students' scientific-process ability, to formulate meaningful science concepts for the students. More important is to lead students to assimilation, self-regulation and accommodation, in order to remove their misconceptions and thus to form a meaningful system of science concepts.

(2) Reading materials

The purpose of reading material is to stimulate student interest in learning, expand their range of knowledge, reinforce the formulation of concepts and extend the application of concepts. Normally, reading material is written in short form according to the following format:

- Based on Ausubel's teaching theories, introducing related science concepts.
- Introducing educational stories of how related concepts were discovered.
- Introducing the application of a certain concept or knowledge in daily life, technology, or industry.

(3) Socratic question

Socratic questions are written in the format of concept-conflict discussion or open-ended discussion in terms of the phenomenon obtained from student experiments. This type of question can lead students to develop cognitive assimilation and self-regulation as well as to remove their misconceptions, and furthermore to create a new structure of cognition.

(4) Self-evaluations

The purpose of self-evaluation is to help the student to find out his own weaknesses and a way of remedying them. Therefore, the format of self-evaluation includes test sheets and answer sheets with remedial instruction. Thus, the student learns how and where to improve himself.

3. Completion of the new teaching material for each unit

According to the theories of constructivism, concept restructuring, and individualized teaching, the new teaching materials are completed as follows:

Chapter 1-1: Force(I) (the core material)
Chapter 1-2: Force(I) (selected material, T2 level)
Chapter 1-3: Force (I) (selected material, T2 level)

Chapter 1-4: Force (II) (selected material, T3 level)
Chapter 2-1: Pressure of fluid (the core material)
Chapter 2-2: Pressure of fluid (selected material, T3 level)
Chapter 3-1: Buoyant Force (I) (the core material)
Chapter 3-2: Buoyant Force (II) (selected material, T2 level)

4. New teaching materials evaluated by subject experts and science teachers

The materials have been evaluated by six professors with expertise in the appropriate subjects and ten senior physical-science teachers. Four of the six professors agree with the mode of design. They pointed out that teaching materials based on experiment and discussion can theoretically develop student learning interest and correct learning attitudes.

The ten senior science teachers' opinions were as follows:

(1) Experiments and discussions serve the function of promoting student motivation and interest because they lead the student to take part in concept- and theory-based teaching activities. They also serve to develop students' attitude toward problem-solving so that students learn to cooperate with each other. Thus the students learn a better way to study science and develop their thinking ability as well as alter their passive attitude toward the study of science.

(2) The teaching material designed so as to include core and selected materials is helpful to students of different levels.

II. Objectives

Instead of training science teachers traditionally, the study proffers teaching handbooks of the new teaching materials to the teachers. Under this condition, the aims of the study are described by the following questions:

Question 1: How is the student learning achievement as well as ability to carry out scientific process enhanced by the new teaching material,?
Question 2: What is the students' evaluation of the new teaching material?
Question 3: What is the science teachers' evaluation the new teaching material? What are its implications?

III. Methods

Methods include study design, instruments, samples, and analyzing methods which are described as follows:

1. Study design

This study compared the experimental group with the control class using the format of $\frac{X\;O\;X}{O\quad O}$ Where "X" represented the exposure of the experimental group to new teaching materials; and "O" represented data collection from student learning achievements, the growth in scientific-process ability, student-perception questionnaire and science teacher-perception questionnaire.

2. Instruments

Four instruments were developed in this study, as follows:

(1) Pretest and posttest on learning achievement2 for each chapter.
(2) Student-perception questionnaire for the experimental group to evaluate the new teaching material. (See Table 2)
(3) Science teacher-perception questionnaire to evaluate the new teaching material.
(4) Scientific process ability test for the students.

There were twelve main questions, which included twenty-four minor questions. Except for Question 1, on classifying ability, and Question 4, on reasoning ability, all of the other questions were concerned with analyzing ability on high levels. Test-retest reliability was 0.65 under $p < 0.001$ (N=95). The validity correlated with the Physical Science monthly test was 0.77, while correlated with the Mathematics monthly test it was 0.82.

3. Samples

Six junior high schools located in different areas of southern Taiwan were chosen based on the appropriateness of new teaching materials to real teaching environments: Shia-Kan (Kaohsiung City), Fong-Shen (Kaohsiung County), Wen-Shan (Tainan City), Han-Shiun (Tainan City but located in an industrialized area), Jang-Shen (Kaohsiung County), and Tre-Chen (Pintung County). Each school had two representative science teachers except Jang-Shen junior high school which had only one science teacher available. One experimental class and one control class were formed from each representative science teacher's classes except at Jang-Shen junior high school, which had two classes instead of one. There were altogether twelve experimental classes and twelve control classes. Due to the limited administration in each school, the experimental classes and the control classes were not of equal size.

4. Data analysis

T-test and frequency statistics were adopted in this study.

IV. Results, Conclusions and Implications

Learning achievement as well as the growth in scientific-process ability at each school and in all the samples, student and teacher evaluations of the new teaching materials, all will be discussed as follows:

1. Learning achievement and growth in scientific process ability

T-test results obtained separately from student learning achievement and scientific- process ability growth before and after each chapter (or unit) are shown in Table 1.

Table 1 indicates that, in terms of the total score in learning achievement of chapter(1+2+3), there is no difference in the results of the T-test between the experimental and control groups under $p < 0.05$. However, if considering only the learning achievement of chapter 3, then the experiment group with respect to the total sample, school 4, and school 5 are both significantly better than the control group, under $p < 0.01$. This figure answers part of the first question pertaining to study objectives, that is, after adjusting themselves to the new teaching materials, the students of the experimental group demonstrate better learning achievement than the students of the control group.

As for growth in scientific process ability, the T-test indicates that the scores of the experimental group are significantly better than those of the control class with respect to the total sample, at school 1 and school 4 (excluding school 2 which will be explained below) under $p < 0.05$, or $p < 0.01$, or $p < 0.001$ respectively.

Excluding the pre-test of each chapter, and the post-test of chapter one which belongs to the adjustment period of the new teaching strategy, Table 1 also shows that only the control group of School 2 is significantly better than the experimental

Table 1. T-test for Student Learning Achievement and Growth in Scientific-process Ability before and after Each Chapter of Teaching between Experimental and Control Group

		Tot	Samp	Schl	1	Schl	2	Schl	3	Schl	4	Schl	5	Schl	6
		DF	T	DF	T	DF	T	DF	T	DF	T	DF	T	DF	T
Chap 1	Pre. T.	995	-2.6*							177	-2.0*				
	Pos. T.			159	2.3*					177	-3.1**	150	2.4*	136	-2.8*
Chap 2	Pre. T.	979	2.5*	141	3.2*					177	5.6***	168	-3.0**		
	Pos. T.														
Chap 3	Pre. T.											168	2.0*		
	Pos. T.	984	3.0**							176	2.8*	147	2.5*		
Chap 1+2+3	Pre. T.											168	-3.5***		
	Pos. T.							176	2.0*						
Scient Proc	Pre. T.											164	-3.9***		
	Pos. T.	983	2.1*	159	3.7***	169	-3.3**			177	2.8*				

Note: 1. *, **, or *** represent $p < 0.05$, $p < 0.01$ or $p < 0.001$ respectively

2. Minus (i.e.-) represents mean scores of experimental group < control group

3. DF=degree of freedom, Scient. proc=scientific process, Tot=total, Samp=sample, Schl=school, Pre. T.=pre-test, Post. T.=post-test, Chap=Chapter

group of the same school in scientific-process ability growth after learning the new teaching materials under $p<0.01$. The reason could be that teachers of the experimental group were inclined to adopt a tra-

Table 2. Percentage Distribution of Questionnaire Q1 through Q13 Evaluated by Students

Item of questionnaire	Options	Total N=498	Schl 1 N[illegible]	Schl 2 N=84	Schl 3 N=86	Schl 4 N=90	Schl 5 N=78	Schl 6 N=65
Q1 The designs of "core unit" and "select unit" are more suitable for me than the textbook.	Agree	47	51	52	47	40	52	37
	No option	43	43	39	40	43	41	54
	Disagree	10	6	9	13	16	7	9
Q2 The designs of "core unit" and "select unit" offer me more choices than the textbook.	Agree	58	65	66	46	49	60	69
	No option	32	24	32	43	36	28	27
	Disagree	10	11	2	11	15	12	4
Q3 The prediction and discoveries activities in new materials help me learn method of observation.	Agree	64	65	71	49	65	70	64
	No option	30	33	28	38	26	23	34
	Disagree	6	3	1	13	8	7	1
Q4 The discussion activity in the new materials help me learn more about thinking than the textbook.	Agree	55	56	63	51	53	55	51
	No option	34	30	28	36	34	33	43
	Disagree	11	14	9	13	13	12	6
Q5 The conflicted problems discussion in new materials helps me understand more than the textbook.	Agree	46	49	54	37	54	37	45
	No option	40	37	37	43	29	53	42
	Disagree	14	14	9	20	16	10	13
Q6 The "self-evaluation" and "explanation" in the new teaching materials help me learn more than the textbook.	Agree	56	52	76	50	63	45	51
	No option	31	37	21	37	28	34	30
	Disagree	13	11	3	13	9	22	19
Q7 The design of "evaluation" in the new materials helps me to better judge what I have learned.	Agree	52	47	63	44	50	60	45
	No option	35	35	32	41	35	28	42
	Disagree	13	18	5	14	15	12	13
Q8 The teaching activities in the new materials are more interesting than those of the textbook.	Agree	51	57	59	44	48	48	51
	No option	37	32	37	42	22	40	40
	Disagree	12	11	5	13	21	12	9
Q9 The teaching activities in the new materials use more demonstrations than those of the textbook.	Agree	58	59	65	54	66	49	54
	No option	32	32	31	34	23	34	43
	Disagree	9	9	3	11	11	17	3
Q10 The teacher usually gave us a lot of time to discuss units such as "Pressure" and "Buoyant force".	Agree	56	59	61	51	59	47	57
	No option	32	32	31	34	27	35	36
	Disagree	12	9	8	14	14	18	7
Q11 The learning style in "Pressure" and "Buoyant force" makes me feel successful.	Agree	37	39	44	32	30	37	42
	No option	44	39	46	39	50	41	49
	Disagree	19	22	10	29	20	22	9
Q12 I agree with adopting the organization of new materials to the Physical Science textbook.	Agree	37	39	34	30	36	41	46
	No option	44	41	51	44	47	41	42
	Disagree	18	20	15	26	17	18	12
Q13 I agree with adopting the leaning mode of new materials to Physical Science.	Agree	37	39	40	37	42	31	33
	No option	45	42	51	44	39	43	55
	Disagree	17	19	9	19	18	25	12

Note: Schl represent experimental school
N=number of sample

ditional teaching method which did not focus on the strategies of new teaching materials. Therefore the first conclusion, which answers the first question of the study objectives, comes from the above analysis, as follows:

Conclusion I

In terms of statistics, after students adjust to the new teaching materials they show a learning achievement and growth in scientific process ability surpassing that of the control group.

2. Experiment group students' evaluation of the new teaching materials

Table 2 shows that, regardless of the differentiations of the six chosen areas, approximately 10%-19% of the students hold an unfavorable opinion of the new teaching material, while 50% of the students hold a favorable opinion. Specifically, 37% of the students hold a favorable opinion according to questions #11 (perception of the learning style of the new teaching materials), #12 (perception of the organization of the new teaching materials), and #13 (perception of the learning mode of the new teaching strategies). On the other hand, students who hold an unfavorable opinion, according to questions #11, #12, and #13 are 19%, 18% and 17% respectively. In general, students' perceptions were consistent with the evaluative opinions held by the subject experts and the senior science teachers, as stated in the previous section. Hence, the evaluations were generally positive and affirmative. Therefore, the second conclusion, which answers the second question of the study objectives, derives from the above analysis as follows:

Conclusion II

The majority of students from the experimental group evaluated the new teaching materials favorably.

3. Teacher evaluation of the new teaching materials after implementation

Teacher evaluation of the new teaching materials is divided into two parts, as follows:

(1) Part I: Advantages and disadvantages of the new teaching materials

This information is obtained from interviewing the science teachers about the new teaching materials, as follows:

Advantages

A. The experimental teaching materials encourage student self-reflection which promotes students' problem-solving ability.
B. Discussion", "Questions", and "Experiments" are the most intriguing parts of the materials, which are relevant to each other, too. These materials can stimulate students to brainstorm. Especially after such Socratic dialogue discussion as concept-conflict discussion or open-ended discussion, a sense of satisfaction is usually shared by the whole class.
C. The students are more interested in learning and have a deeper perspective when the concepts of physical science are taught through experiment and discussion.
D. The students can understand the content easily through Socratic dialogue discussion.
E. Forcing students to think or to discuss certain related questions before laboratory teaching usually makes student learning and class teaching more interesting.
F. Most of the guidance modes presented in the new teaching materials are good and practical.
G. "Socratic questions" in each chapter enable the teacher to discover the students' cognitive structure and misconceptions, thus helping reinforce correct concepts for students. Besides, regarding the conflict concepts, the discrepancy between the predictions and the results of the experiment can help students adjust their cognitive structures and gain knowledge.
H. The concept of force in the new teaching material is taught gradually and continually. Therefore, the students are able to apply this solid foundation of knowledge to their daily life.
I. The vast variety of materials can meet individual needs, especially the selected materials.

Disadvantages

A. Although the new teaching material is written in compact format, it involves too many subtle terms or concepts that lack sufficient explanation to provide students with enough background knowledge. Hence, we had to spend lot of time explaining and were unable to teach the most important concepts adequately. On the other hand, the standard textbook offers menu-type explanations both in the experiments and the textual content, which helps students learn more easily. Also it makes teaching simple.

B. Some levels of the Socratic questions, such as concept-conflict discussion or open-ended discussion, are too difficult. Even more, some of these contents are too fuzzy to let the student find the correct answer. Therefore, the majority of students could not proceed with the material without teacher guidance. Conversely, there are more detailed explanations with clearly standardized answers in the standard textbook.

C. Because the level of the majority of students was below the median, and, the new teaching materials were devoid of any detailed explanations or clear-cut answers, we needed to spend a lot of time reinforcing the concepts or principles for the students.

D. Progress was usually behind schedule because teachers had to spend too much time maintaining classroom order during the open discussion period.

E. Most of the "selected materials" and the "self-evaluation" were suitable for students of high achievement levels but not for the others.

F. Some of the concepts needed for the self-evaluation were not taught in the materials.

I. Lower-achievement-level students were usually lost during the period of individualized teaching.

Analyzing the advantages and disadvantages carefully reveals that an unhappy balance exists between the advantages and disadvantages, many pairs of which were chosen by the same teacher. For example, Advantage G and Disadvantage B were provided by the same teacher. We discovered that he not only agreed with the design of the new teaching materials, but also liked the traditional, so-called recipe-style design of the experiments. The reason could be that the teacher's value system had not been transplanted based on a constructivist view. Another, similar, example is that of the teacher who provided Advantage E and Disadvantage A. The key cause of these conflicts lies in the teachers' misconception of the philosophy of science and science learning. Disadvantage C stems from the teacher's incorrect teaching method. Synthesizing the above opinions, however, three amendments are needed as follows:

A. Part of the new material descriptions need to be modified.

B. Part of the new material content is too difficult and needs to be re-examined.

C. Part of the self-evaluation is too difficult and needs to be re-examined.

Finally, the disadvantages also indicate their irrelevance to the design concept of the new materials. Instead, the disadvantages have only to do with the content and the level of the new teaching materials. This leads to the third conclusion, which partly answers the third question of the study objectives, as follows:

Conclusion III

The teachers of the experimental group were favorably impressed by the new teaching materials. They appreciated the materials' regard for students' ability to reflect and to apply what is learned to their daily life. The materials also enhanced the students' learning interest as well as their ability to solve problems.

(2) Part II: Teachers' view of how the new teaching material affects their students

What were the most interesting and the most difficult parts of the new teaching materials for the students from the teachers' point of view? Further, are the teaching materials appropriate when no pressure comes from both the need to keep up with the schedule and to pass the national entrance examination? The interview data show the following:

Reasons for difficulty in teachers' view

A. Students do not know where to find relevant data to solve problems. Neither do they know how to discuss questions.

B. It is difficult for the students to accept an open-ended discussion or concept-conflict discussion format in class. Besides, the students lack an active attitude in learning .

C. Students with poor grades need the teacher to remind them of, and to reinforce in them what is to be learned. In other words, they cannot think and learn independently.

D. Even after the key points of the experiment have been taught by the teacher, some students still do not know how to start the experiment.

E. Explaining the concepts and principles in terms of experimental results is the most difficult part for the students .

F. Students do not know how to proceed with the experiment without the teacher's guidance.

G. Students feel that the most difficult part of the

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new teaching material is that the experimental learning section has no attached conclusion or explanation, for students have always depended totally on their teacher's textbook's explanations in the past.

H. "Concept-conflict discussions and open-ended discussions" are the most difficult parts of the new teaching material.

I. Tests are the most difficult part for students.

Reasons for student interest in teachers' view

A. Group-discussion activity.

B. Group-experiments activity.

C. Concept-conflict discussions and open-ended discussions.

Teachers' opinions if under no pressure to keep up with the unified schedule

A. The new teaching materials are suitable for teaching a small class.

B. The materials are on the average, quite good (four teachers held this opinion).

C. The materials suit high-level students. They are too difficult and abstract for low-level students.

D. The materials suit students of middle or higher levels.

E. With further modification or elimination of difficult contents, the materials may suit all students regardless of their levels (three teachers held this opinion).

It is interesting to note that the reasons for student interest and for their difficulty from their teacher's viewpoint coincidentally fall into the same types of teaching activities, namely group-discussions, group-experiments, and the Socratic questions, which include concept-conflict discussion and open-ended discussion. Why? The reasons may account for the nature of the challenge and fascination of science. Again why do these activities happen to be the most difficult parts of student learning? It has something to do with our "padding" of education. The students never have access to free and open discussion in class. The basic activities of the scientific process such as the design of the experiment, prediction, observation, handling the experiment independently, and discussion, etc., never become familiar to the students. All experiments in the textbook are recipe-style so that the students can understand their experimental results from the textbook. Therefore, the first implication is obtained, which partly answers the third question of the study objectives, as follows:

Implication I

Science teaching must give students credit for a certain degree of scientific ability, and educate its students to do each part of the experiment independently, including prediction, observation, measurement, taking records, and discussion in groups as well as by the whole class. These are the most important factors in motivating students to learn.

Without the pressure of keeping up with the schedule and preparing their students for the national entrance examination, the teachers seem to have a favorable opinion of the new materials. Thus, a second implication is reached, which partly answers the third question of the study objectives, as follows:

Implication II

Concern about keeping up with the teaching schedule and preparing students for the national entrance examination weakened some teachers' favorable opinions of the new teaching materials.

V. Suggestions

Synthesizing the conclusions and the implications of this study, the following suggestions seem appropriate:

A question ensued from the first and the second conclusions: what enhances student learning achievement regarding the new teaching materials and what makes them like the materials? We have gained an answer in the third conclusion. Therefore, two suggestions can be made:

Suggestion I

Science teaching as well as curriculum design must encourage students in independent reflection and learning. They also must enable the students to apply what has been learned to their daily life. For the purpose of achieving this goal, class teaching must be geared for activity involving two-way discussion.

In fact, science teachers seem to be well aware of the need to implement the first suggestion, i.e. two-way discussion. They also agree with the idea of new teaching materials with teaching strategies described in a teaching handbook. However, their teaching style, as revealed in video tape analysis, still shows that they only know how to employ traditional teaching methods. This dilemma is worth pondering. In fact, this

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is a trait shared by other science teachers of secondary schools. Therefore, we arrive at a second suggestion, as follows:

Suggestion II

Teaching strategies relating to the philosophy of science teaching, cognitive science, and theories of science learning, etc., in normal universities of Taiwan must be re-examined and re-evaluated.

Suggestion III

Finally, a curriculum underlining the importance of the theories and related teaching strategies mentioned in this study is appropriate for science education in Taiwan. It would be worthwhile to do a deeper study and implement it.

References

Bodner, G.M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63*(10), 873-878.

Chiang, Shing-ho (1991). *A study on the development of natural science concepts and their diagnostic instruction in the ROC* (II): *A diagnostic analysis on the cause of misconceptions of buoyant force for middle school students and its remedial strategies.* Taipei: National Science Council of R. O. C. (In Chinese)

Cleminson. A. (1990). Establishing an epistemological base for science teaching in the light of contemporary notions of the nature of science and of how children learn science. *Journal of Research in Science Teaching, 27*(5), 429-445.

Driver, R. & Oldham, V (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13*, 105-122.

Duschl, R. (1990). *Restructuring science education: The role of theories and their importance.* New York: Teachers College Press.

Hewson, P. W. & Hewson, M. G. A. (1988). An appropriate conception of teaching science: A view from studies of science learning. *Science Education, 72*(5), 597-614.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. *Science Education, 72*, 19-40.

Hsu, Rong-fu, Yang, Wen-chin, & Hung, Jeng-fung (1990). The theoretical basis and contents analysis of the learning cycle-New reflections on teaching concepts in physics. *Journal of Physics Learning Society, 12*(5), 375-398. (In Chinese)

Hsu, Rong-fu (1992). *Science of scientific education and cognitive science.* Paper presented at the 8th Conference on Science Education in R. O. C. (In Chinese)

Guo, Chung-chi (1992). A study from the point of view of constructivism on the improvement of mathematics & physics teaching in primary & secondary school. *National Science Council Monthly, 20*(5), 548-570. (In Chinese)

Kuhn, T. S. (1970) *The structure of scientific revolution.* 2nd ed. Chicago: The University of Chicago Press.

Leinhardt, G. & Greeno, J. G. (1986). The cognitive skill of teaching. *Journal of Educational Psychology, 78*(2), 79-85.

Nussbaum, J. (1989). Classroom conceptual change: Philosophical perspectives. *International Journal of Science Education, 11*, 530-540.

Piaget, J. (1964). Cognitive development in children: Development and learning. *Journal of Research in Science Teaching, 2*, 176-186.

Piaget, J. (1974). Translated by Coltman. D. (1980). *Experiments in contradiction.* Chicago:The University of Chicago Press.

Pope, M. L. & Keen, T. R. (1981). *Personal construct psychology and education.* Londres: Academic Press.

Pope, Maureen & Gilbert, J. (1983). Personal experience and the construction of knowledge in science. *Science Education, 67*(2), 193-203.

Posner, G. J., Strike, K. A., Hewson, P.W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education 66*(2), 211-228.

Reif, F. (1987). Instructional design, cognition, and technology: Applications to the teaching of scientific concepts. *Journal of Research in Science Teaching, 24*(4), 309-324.

Shuell, T. J. (1986). Cognitive conceptions of learning. *Review of Educational Research, 56*, 411-436.

Strike, Kenneth A. & Posner, G. (1982). Conceptual changes in science teaching. *European Journal of Science Education, 4*(3), 231-240.

Vosniadou, S. & Brewer, W. F. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*(1), 51-67.

應用建構理論設計國中理化科單元教材的實證研究

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摘　要

本研究係將應用建構式課程設計理論、概念重建理論及個別化教學理論等所設計的新單元教材，交由代表台灣南部的院轄市區、省轄市區、鄉鎮縣轄市區、沿海漁鹽區、及偏遠山地區等不同教學環境的六所國民中學進行實驗組對控制組的比較實證研究。在五所國民中學中，各選出二位代表性的科學教師，又在科學教師任教的班級中，各選出一班爲實驗班，另一班爲控制班。另一所代表偏遠山地區的學校，因理化教師很少，故只能從一人所教的班級中，選二班爲實驗班，另二班爲控制班。

研究設計爲 $\frac{XOX}{O\ \ O}$，其中〝X〞表示新教材的教學，而〝O〞表示資料收集，其量具有四，分別爲：(1) 各單元教材的前後測試題，(2) 學生學習實驗教材後之評價問卷，(3) 實驗組教師對教學相關問題的看法調查，(4) 做爲前後測之用的科學過程能力測驗。研究結果顯示，新教材受到學生正面的評價，且其教學成效超過原來理化課本的教學成效。新教材亦受到科學教師的正面評價，尤其認爲新教材重視學生自我省思、實際生活上的應用問題，及問題討論，有利於協助學生發展解決問題的能力，並提高學習的興趣。

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Promoting Open-ended Thinking on the STS Topic : "Detergent"

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ABSTRACT

Teachers are central for success in STS education. It is important to promote teachers' open-ended thinking on STS topics.

Inservice teachers enrolled in a summer institute at National Taiwan Normal University were instructed to use the interpretive structural modeling (ISM) to promote their open-ended thinking on the STS topic, detergent. Their descriptive statements and STS maps subsequently drawn with the ISM method reflected their open-ended thinking on the STS topic. Their levels of cognitive complexity on the STS views were scored on the McDaniel's 5-point scale. The results showed that the ISM method can promote teachers' views on the STS topic in real life.

Keywords: STS, ISM, metacognition, detergent

I. Introduction

Today's citizens are faced with personal and social choices that are beyond the scope of traditional values: global warming, ozone layer, genetic screening, strategic defense in space, and release of genetically engineered organisms into the environment.

1. The STS movement

Various concepts of science, technology, and society (STS) education were created and developed during the 1980s and have been implemented in some parts of the world in the 1990s. There is already sufficient evidence to suggest that the concepts of STS education promise to deliver a new type of curriculum required for citizens of the science and technology-prominent society (Yager, 1992). Superordinate goals emphasized by STS science education include high-level thinking, higher-order cognitive skills, creativity, ethical considerations, values clarification, global view, career awareness, decision-making, and problem-solving capacity for citizenry. Consequently, all citizens will have understanding of the interactions among science, technology, and society. They will also have the ability to intelligently evaluate technological and scientific activities in the socio-technological context. This ability will enable them to take a meaningful, active part in the democratic decision-making process (Yager, 1992; Zoller, 1991). Hines (Hines, Hungeriord, & Tomera, 1987) completed a meta-analysis of extant literature in environmental education on action behavior. Sia (Sia, Hungerford, & Tomera, 1986) and Hines each concluded that citizens acting on environmental issues possess four characteristics: (a) They are aware of issues; (b) They are knowledgeable about actions that might be taken to resolve the issues ; (c) They have the ability to act on issues; and (d) They possess certain personality and attitude characteristics that make them act.

2. STS learning framework

In order to achieve the STS learning goals, Waks (1992) designed an organizing framework to help edu-

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cators identify, select, organize, and sequence learning experiences to promote responsible citizenship in this technologically dominated society. The phases of learning cycles are: phase 1, self-understanding; phase 2, study and reflection; phase 3, decision making; and phase 4, responsible action. Marzano (1992) also proposed dimensions of learning to improve the quality of learning on an issue-related task. The dimensions of learning are: dimension 1, positive attitudes and perceptions about learning; dimension 2, acquiring and integrating knowledge; dimension 3, extending and refining knowledge; dimension 4, using knowledge meaningfully; and dimension 5, productive habits of mind. In dimension 2, Marzano suggested graphic organizers be used to integrate knowledge.

3. Metacognitive strategy

The heuristic of concept-mapping has been used as a metacognitive strategy that helps learners (1) link prior knowledge to new information, (2) understand concepts and relationship between them, and (3) see the hierarchical, conceptual, and prepositional nature of knowledge (Klausmeier, Ghatala, & Frager, 1974). Interpretive structural modeling (ISM) is a tool used for understanding the relationships among a number of elements. It was developed by Warfield (1976) based on a graphic representation of the matrix in the form of a directed graph. Either manually or with the aid of a computer, logical relationships are determined among the generated element set and the contextual relationship. Mapping can be a valid and reliable way of integrating and summarizing a set of perceived units of reality (Warfield, 1976; Wang, 1991). The procedures of constructing ISM charts are as follows: (a) Elements are abstracted from the contents of the STS issue. (b) Relationships between the elements are located. (c) Structural arrangement of these elements is determined.

4. Measurement of open-ended thinking

Creating appropriate measures for a new set of STS learning outcomes requires a major effort in research and development. Past attempts to measure thinking are based on the assumption that thinking is dictated by formal, logical rules such as used in deduction and induction. Tests based on these assumptions such as the Watson-Glaser Critical Thinking Appraisal use multiple-choice questions to measure these formal skills (McDaniel & Lawrence, 1990). Alkenhead and Ryan (1992) produced an assessment instrument dealing with STS topics, Views on STS (VOSTS). VOSTS is a pool of 114 multiple-choice items that address a broad range of STS topics. The items were developed empirically over a six-year period with grade 11 and 12 Canadian students. Objectivistic evaluation methods, like criterion-referencing, are not appropriate for evaluating learning from constructivistic environments. The methods by which we evaluate learning from real-world context should be more goal free and should assess knowledge construction that represents multiple perspectives and viewpoints (Jonassen, 1991). McDaniel and Lawrence (1990) considered thinking a matter of perceiving, organizing, and interpreting information. Within this framework they experimented as follows: Students responded to a 15-minute videotape about the production of nuclear weapons and the resulting environmental pollution; they were asked to write their interpretations of this situation. Their scoring rationale is so designed to provide an index of the cognitive complexity reflected in the students' responses. The rater assigns one of the following five levels which indicate the level of cognitive complexity reflected in the student's reaction and in terpretation in writing. Each of these levels is defined below.

Level 1: Unilateral Descriptions. The student (i) simplifies the situation, (ii) focuses on one idea or argument, (iii) brings in no new information, meanings, or perspectives, (iv) makes good/bad, either/or assertions, (v) appeals to authority or simple rules rather than supporting ideas, and (vi) repeats or paraphrases information presented.

Level 2: Simplistic Alternatives. The student (i) identifies simple and obvious conflicts without pursuing or analyzing, (ii) develops a position by dismissing or ignoring one alternative and supporting the other with assertions, and (iii) does not make deeper assessment of the situation.

Level 3: Emergent Complexity. The student (i) identifies more than one possible explanation or perspective, (ii) establishes and preserves complexity, (iii) introduces new elements, and (iv) supports position through comparisons and causal statements.

Level 4: Broad Interpretation. The student (i) uses broad ideas to help define and interpret the situation, (ii) manipulates ideas within the perspective established, (iii) has a clearly recognizable explanatory theme, and (iv) integrates ideas into "subassemblies," each supporting a component of the explanation.

Level 5: Integrated Analysis. The student (i) restructures or reconceptualizes the situation and approaches the problem from a new point of view, (ii) constructs a network of cause-and-effect relationships, (iii) integrates and extrapolates ideas, (iv) arrives at new interpretations by analogy, application of principles, generalizations, and world knowledge, and (v) constructs an organizing framework, links connections, and predicts consequences (McDaniel & Lawrence, 1990).

5. Teachers' role in science-curriculum reform

In the center-periphery model of the 1960s' science curriculum reform, goals and contents were developed by experts (center) and implemented by teachers (periphery) (Hart & Robottom, 1990). Yager (1992) pointed out that during the 60's much help was provided to teachers, so that they would not stray from the well-structured reformed curriculum. Unfortunately, as soon as funding to support the activities was withdrawn, science education problems looked very much like those existing before 1957. Yager further pointed out that teachers are central to any solutions and successes for current reform efforts. Teachers in the 90s must internalize STS goals, master the basic concepts and skills needed, and be willing to abandon standard textbooks.

STS education is distinctly different from the type of curriculum, instruction, and evaluation found in traditional science classrooms. It is different from what teachers were prepared to deliver (Rubba, 1991). The beliefs and the values that direct the practice of science teaching by a science teacher have been constructed out of science education and science teacher education that they received and their own science-teaching experiences. Before ap-propriate STS teaching can be fully developed and put into practice, science teachers' beliefs and values must be compatible with the notion of STS education. STS teacher education will be successful only if we employ strategies that help science teachers construct appropriate beliefs and values as they learn to understand STS education. Teachers must rethink the role they play in the development of STS education, reflecting the shift in values, the need for an increased knowledge base, and implementation of processes that convey knowledge while including students in active, participatory learning (Rubba, 1991).

Our research group has been engaging in a research project to develop an STS module Detergent. This study stands on the following two beliefs. (1) The reform process of STS oriented education should be participatory and research based. Divisions of labor between practitioners and evaluators should be eradicated. (2) Citizens literate in STS must be cultivated through STS related social issues. The very first activity in the cultivation is to promote teachers' awareness of STS issues.

The possible use of the Interpretive Structural Modeling (ISM) as a metacognitive strategy to promote open-ended thinking on an STS topic has not been addressed. This study was undertaken to find out if the ISM could serve as a tool to help teachers promote their awareness of and views on the issue "detergent." Their open-ended thinking was measured by McDaniel's 5-point scale method.

II. Methods

1. Subject

The subjects of this study waere 64 inservice teachers participating in a summer training program (1992) in the Department of Chemistry, National Taiwan Normal University (NTNU). The characteristics of the teachers involved were as follows: (a) 58 junior-high-school teachers; (b) 3 high-school teachers; and (c) 3 vocational-high-school teachers.

2. Instructional media

The instructional media consisted of two scenarios and STS vignettes that were prepared to motivate and maintain students' interest in the topic, "Detergent." Scenario One was about a swan swimming peacefully on a lake. Scenario Two was about a swan struggling to float on the lake. STS vignettes consisted of a short illustrative story and challenging questions and paradoxes related to STS issues. One example of the questions is: What must we do to prevent adverse influences of using detergents?

3. Scoring method for the views on the topic

The teachers' levels of cognitive complexity on the STS views were scored on the McDaniel 5-point scale as described above. The test examples and the authors' rating in the book (McDaniel & Lawrence, 1990) were used for interrater reliability (Appendix 1).

4. Instruction/measurement strategies and procedure

After viewing two scenarios and STS vignettes on the topic, participants were instructed to take time to (a) reflect on what they had heard and seen and (b) describe and explain their thoughts as completely as possible. Participant responses ranged in length from half to one-and-half pages, hand written. The responses were collected and copied for scoring. After a break the written responses were handed back to the participants. The participants were then asked to draw STS maps using the ISM method. The participants' abilities in using ISM to construct STS maps were trained through a model program as described below. In constructing the STS maps using ISM as a graphic metacognition tool, the learners were expected to: (a) link the topic with other knowledge within a discipline, with other disciplines, and with social and global problems; (b) understand the overall structural relationships among the elements in the topic; (c) understand the relationships among the prerequisites already known and the present learning elements; and (d) apply the process skills already learned to a new topic.

The model program was carried out as follows: (a) The instructor gave each learner a completed structured STS-map of a topic to explain the related elements and their structural relationships. (b) The learners should be aware of what they are learning. (c) The learners identify the learning elements, distinguish the ones they have or had not learned, and determine their structural relationships. (d) The learners are allowed to enter notes on maps.

III. Results and Discussion

Inservice teachers enrolling in a summer institute (1992) at NTNU were introduced to the instructional media on the STS topic "Detergent." The participants' hand-written statements reflecting their views on the topic were collected. Their levels of cognitive complexity on the STS-views were scored on the McDaniel 5-point scale (the first and second assessment, Tables 1 and 2).

Table 1 lists the numbers of participants at each level according to the classification: male, female; junior, senior, vocational high-school teachers; years of teaching experience; educational background; the locations of schools they teach at. The means (M) are used in describing the teachers' average performance in each group. The standard deviations (SD) show the spread of teachers' performances (variability) in the group. It is seen that no one was at level 5. The males' levels ranged from 1 to 4 (M 2.31, SD 0.666), being mostly at level 2 (22 persons, 62.9%) followed by level 3 (9 persons, 25.7%). The females were mostly at level 3 (19 persons, 65.5%; M 2.93, SD 0.583) indicating that the females were more enthusiastic. The standard deviation for the female was smaller than that for the male, indicating smaller spread of performance (less variability). The larger standard deviation for the male shows the larger spread in the levels of cognitive complexity. The junior-high-school teachers were mostly at levels 2 (27 persons 46.6%), and 3 (25 persons, 43.1%).

Those with 6-10 years of teaching experience were mostly at level 2 (17 persons, 47.2%) and level 3 (15 persons, 41.7%). Those with more than 10 years of teaching experience are mostly at level 2 (10 persons, 40.0%) and level 3 (11 persons, 44.0%; M 2.64, SD 0.742). Higher variability in performance was observed for teachers with more than 10 years' teaching experience than those with fewer years.

Graduates of normal universities and other universities, and those teaching in urban, rural, or isolated islands, were again mostly at levels 2 and 3. High variability in performance was also observed for those in urban (M 2.66, SD 0.635), and rural (M 2.44, SD 0.892) areas. The data for all others not mentioned are insignificant because of the small numbers of persons.

The participants were instructed to use interpretive structural modeling (ISM) to construct STS maps on the topic. Teachers' views on the topic as observed on the maps were scored again using McDaniel's method (the second assessment, Table 2). Four ISM charts drawn by teachers are shown in Appendix 2.

Table 2 shows that there were improvements in views on the STS topic. The males rose to level 3 (16 persons, 45.7%) and level 4 (14 persons, 40.0%; M 3.23, SD 0.770) from levels 2 and 3 in Table 1. The females also progressed to level 3 (12 persons, 41.4%) and level 4 (12 persons, 41.4%; M 3.24, SD 0.739) from levels 2 and 3 in Table 1. Interestingly, the males caught up with the females. The junior-high-school teachers also progressed to levels 3 (26 persons, 44.8%) and 4 (24 persons, 41.4%; M 3.28, SD 0.696) from levels 2 and 3 in Table 1. Those with 6-10 years and more of teaching experience progressed to levels 3 and 4 from levels 2 and 3 in Table 1. All other groups of teachers in Table 2 also progressed to levels 3 and 4 from levels 2 and 3 in Table 1. Still, not a single person attained level 5. The results of the second assessment (ISM method, Table 2) also indicate higher variability in performance for males than females.

Table 1. The First Assessment of the Levels of Views on The STS Topic "Detergent" (Description Method)

Level / Group	1	2	3	4	5	Mean Value (M.)	Standard Deviation (S. D.)	Total
Male	2	22 (62.9)	9 (25.7)	2	0	2.31	0.666	35
Female	0	6 (20.7)	19 (65.5)	4	0	2.93	0.583	29
Junior High	1	27 (46.6)	25 (43.1)	5	0	2.59	0.670	58
Vocational High	0	0	2	1	0	3.33		3
Senior High	1	1	1	0	0	2.00		3
Teaching Experience 1-5 Years	0	1	2	0	0	2.67		3
6-10 Years	1	17 (47.2)	15 (41.7)	3	0	2.56	0.685	36
>10 Years	1	10 (40.0)	11 (44.0)	3	0	2.64	0.742	25
Normal Univ. Graduates	2	26 (44.1)	26 (44.1)	5	0	2.58	0.700	59
Other Univ. Graduates	0	2 (42.6)	2 (48.9)	1	0	2.80	0.836	5
Teachers in Urban Schools	0	20 (42.6)	23 (48.9)	4	0	2.66	0.635	47
Teachers in Rural Schools	2	7 (43.8)	5 (31.3)	2	0	2.44	0.892	16
Teachers on Isolated Islands	0	1	0	0	0	2.00		1

Figures represent numbers of persons.
Figures in parentheses are percentages

The results of the first and the second assessments were again compared in Table 3. McDaniel's levels 1 and 2 were combined into the lower level in Table 3, because the learners' responses were mostly descriptions of the situation. Levels 3 and 4 were combined into the higher level, because the learners were able to explain how parts of the situation were interconnected (levels 3 and 4), their responses being noticeably analytic (levels 4). For the whole class, the use of ISM brought an increase of 66.7% from lower to higher levels; for males, 79% and for females, 17%. The small increase in females was due to initial high performance. For junior-high-school teachers, the increase was 71.4%; for senior-high-school teachers 50%; for vocational-high-school teachers 0%. The data for the last two categories are less significant because of the small numbers of persons. For those with teaching experience of more than 10 years, the increase was 54.5%; for those with 6-10 years 72.2%; for those with less than five years 50%. For graduates of normal universities, the use of the ISM method

Table 2. The Second Assessment of the Levels of Views on The STS Topic Detergent (ISM Method)

Level / Group	1	2	3	4	5	Mean Value (M.)	Standard Deviation (S. D.)	Total
Male	1	4	16 (45.7)	14 (40.0)	0	3.23	0.770	35
Female	0	5	12 (41.4)	12 (41.4)	0	3.24	0.739	29
Junior High	0	8	26 (46.8)	24 (41.4)	0	3.28	0.696	58
Vocational High	0	1	2	0	0	2.67		3
Senior High	1	0	0	2	0	3.00		3
Teaching Experience 1-5 Years	0	0	0	3	0	4.00		3
6-10 Years	0	5	16 (44.4)	15 (41.7)	0	3.28	0.701	36
>10 Years	1	4	12 (48.0)	8 (32.0)	0	3.08	0.812	25
Normal Univ. Graduates	1	10	25 (42.4)	23 (39.0)	0	3.19	0.776	59
Other Univ. Graduates	0	0	2	3	0	3.60	0.548	5
Teachers in Urban Schools	0	6	20 (42.6)	21 (44.7)	0	3.32	0.694	47
Teachers in Rural Schools	1	3	8 (50.0)	4 (25.0)	0	2.94	0.854	16
Teachers on Isolated Islands	0	0	0	1	0	4.00		1

Figures represent numbers of persons.
Figures in parentheses are percentages

brought an increase of 60.7%; graduates of other universities, 100%. Those teaching in urban schools attained an increase of 70%; those of rural schools 55.6%; and those of isolated islands, 100%. The two 100%'s are less significant because of the small numbers of persons.

The increments in the two assessments (Table 3) showed that the ISM method can promote open-ended thinking and improve teachers' views on the STS topic in real life. The facts suggested that ISM can help teachers to (a) link the topic with other knowledge within a discipline, with other disciplines, and with social and global problems; (b) understand the overall structural relationships among the elements in the topic; (c) understand the relationships among the prerequisites already known and the present learning elements; (d) apply the process skills already learned to a new topic, find out similarities and differences, analyze, support, and elaborate on a situation. With McDaniel's measurement the ISM method was thus found effective in promoting

Table 3. Comparison of the Two Assessments of the Levels of Views on the STS Topic "Detergent"

	First Assessment		Second Assessment		Percent
	Low Level	High Level	Low Level	High Level	Increment*
Whole Class	30	34	10	54	66.7*
Male	24	11	5	30	17.0
Female	6	23	5	24	17.0
Junior High	28	30	8	50	71.4
Senior High	0	3	1	2	0.0
Vocational High	2	1	1	2	50.0
Teaching Experience 1-5 Years	1	2	0	3	50.0
6-10 Years	18	18	5	31	72.2
> 10 Years	11	14	5	20	54.5
Normal Univ. Graduates	28	31	11	48	60.7
Other Univ. Graduates	2	3	0	5	100.0
Teachers in 4 Urban Schools	20	27	6	41	70.0
Teachers in Rural Schools	9	7	4	12	55.6
Teachers on Isolated Islands	1	0	0	1	100.0

Figures represent numbers of persons
*(30–10)/30=66.7%

views on STS topics. However, level 5 was not attained.

IV. Conclusion

The results of this study seem to show that the ISM method can promote open-ended thinking and improve teachers' views on the STS topic in real life. Here, metacognition overlaps with the constructivist view of learning in which learners generate their own understanding of real-world problems. ISM served as a metacognitive tool to help teachers link prior knowledge to a new problem, organize, construct, modify, and elaborate their cognitive frameworks to promote views on the STS topic.

Most preservice and inservice teachers in our community still see science as a large body of information to be mastered. They less often consider it as a method for constructing new knowledge about the universe. Teachers are central for the success in STS education. When science teachers' beliefs and values become compatible with notion of STS education, appropriate STS teaching will fully develop. Then we will be able to educate students to become citizens who can take a meaningful, active part in the democratic decision-making processes. The model of learning/measurement using ISM and McDaniel's scoring methods can be useful in reforming science education. The module "Detergent" can be used in the organic chemistry section of secondary-school physical-science courses.

Acknowledgments

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References

Alkenhead, G. S., & Ryan A. G. (1992). The development of a new instrument: Views on science-technology-society(VOSTS). *Science Education*, *76*(5), 477-491.

Hart, E. P., and Robottom, I. M. (1990). The science-technology- society movement in science education: A critique of the reform process. *Journal of Research in Science Teaching*, *27*(6), 575-588.

Hines, J., Hungerford, H., & Tomer, A. (1987). Analysis and synthesis and of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education*, *18*(2), 1-8.

Jonassen, D. H. (1991). Evaluating constructivistic learning. *Educational Technology*, *31*, 28-33.

Klausmeier, H. J., Ghatala, E. S., & Frayer, D. A. (1974). *Conceptual learning and development: A cognitive approach*. New York: Academic Press.

Marzano, R. J. (1992). *A different kind of classroom: Teaching with dimensions of learning*. Association for Supervision and Curriculum Development, Alexandria, VA.

McDaniel, E., & Lawrence, C. (1990). *Levels of cognitive complexity, An approach to the measurement of thinking*. New York: Springer Verlag.

Rubba, P. A. (1991). Integrating STS into school science and teacher education: beyond awareness. *Theory into Practice*, *XXX*, No. 4, 303-308.

Sia, A., Hungerford, H., & Tomera, A. (1986). Selected predictors of responsible environmental behavior: An analysis. *Journal of Environmental Education*, *17*(2), 31-40.

Waks, L. J. (1992). The responsibility spiral: A curriculum framework for STS education. *Theory into Practice*, *XXXI*, No. 1, 13-19.

Wang, C. H. (1991). *STS program-ISM approach*. Presented at XVII Pacific Science Association Congress, University of Hawaii, Honolulu, Hawaii, May 27-June 2.

Warfield, J. N. (1976). *Societal System*. New York: John Wiley & Sons, 204-284.

Yager, R. E. (1992). What we did not learn from the 60s about science curriculum reform. *Journal of Research in Science Teaching*, *29*, 906.

Zoller, U. (1991). Teacher's beliefs and views on selected Science-technology-society topics: A probe into STS literacy versus indoctrination. *Science Teacher Education*, *75*(5), 541-542.

Appendix 1.

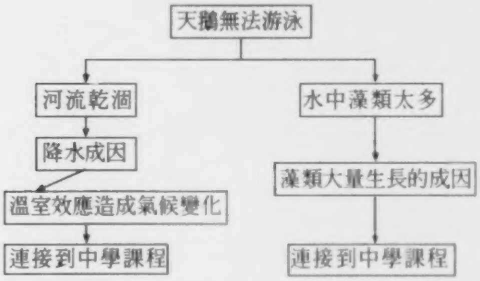
Test Examples

1. Bomb Factories: Since life comes before anything else it is only human nature to protect it. The reasoning behind why there are weapons and why they are being produced is simple, it is for national defense of the U.S. to protect the lives of American citizens; but there is no justification for building nuclear plants or not shutting down nuclear plants after the harm of these plants has been recognized. The U.S. government's reason for building nuclear plants is to protect the citizens of the U.S., not harm them. I am shown that in this day and age with distrust between countries, weapons are necessary, but having enough weapons to destroy the Earth three times is just ridiculous. Therefore I must say that building nuclear weapons is not justified. Before the time of nuclear weapons wars were limited to the countries and the generation that the war occurs in, but now not only will it destroy a generation, but as we have seen in Japan, it will harm the next. The U.S. made a big deal about the Chernobyl plant, well it should turn around and take a look at our own plants. After all, nuclear weapons were made to protect the U.S. not destroy it.
2. Bomb Factories: I think it is really sad that these people, for one thing, stay there! I would move so I wouldn't stay there. If there has been more than one case of people getting cancer then why stay there. Something should be done about the places that are making the weapons. They are supposed to be making them to defend us not to kill us!! I really think that they shouldn't be made in the first place then everybody will be safe. As for Zinser, I think he should sue them for his two boys cancer!! They have to go through a lot of pain and so does he and its only fair for the people at this plant to feel it too.
3. Bomb Factories: I think it is ridiculous that factories are doing so much damage and nothing is being done about it. Sure the factories make bombs, which will be used to kill the enemy. What they are doing isn't just killing the enemy, but their own people. They are letting all of this bad material into the atmosphere, which is causing a lot of people to get cancer. It seems to me that the people running these factories don't care about anything but making bombs. They must have demented minds. I don't know how anyone could want to make bombs. In a sense they are murderers. They kill the people around the factories and when they set the bomb off, it will kill millions of people. I'm sorry, I really don't see why we need to make bombs. God created us and he should be the one to destroy us, not ourselves.
4. Bomb Factories: Through the tape and magazine articles many problems were mentioned. I feel that America needs to work with these problems. Why I feel this way is because it has killed and endangered many lives. I know that the United States thinks that having weapons are important, but in the process of making these weapons they are killing their own people.
5. Bomb Factories: The government is really stuck in a position it is hard to get out of. They should have started 10 years ago. This may be just a political ploy to get the U.S. citizens in the mood for spending billions on the factories, after all there are not mass numbers of people dying. The Executives & Engineers work in the factory too and they are the people supposedly pushing production. I think it does hurt the environment. But so does all industry. They could make it a bit better for the workers & surrounding residents but there is risk involved in everything. This is also boring cuz I've seen it before!

Answers to Test Examples

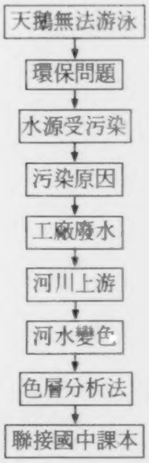
1. Level 5
2. Level 1
3. Level 2
4. Level 4
5. Level 3

Appendix 2. Four ISM Charts Drwas by Teachers
ISM法的實例


天鵝無法游泳
河流乾涸
降水成因
溫室效應造成氣候變化
連接到中學課程
水中藻類太多
藻類大量生長的成因
連接到中學課程

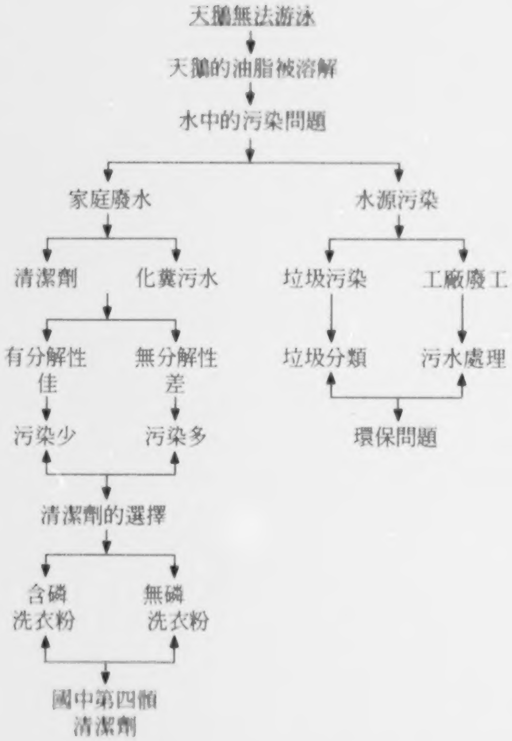
此ISM圖只提出河流乾涸及水中藻類太多爲天鵝無法游泳的原因，但並沒有進一步說明是什麼原因造成河流乾涸及水中藻類太多。

故爲階層一


天鵝無法游泳
環保問題
水源受污染
污染原因
工廠廢水
河川上游
河水變色
色層分析法
聯接國中課本

此ISM圖提出了河川上游的工廠排放之廢水爲造成河水變色受污染的原因。其只單純考慮了一個導致污染的因素，而對其他可能的因素則未加以考慮，且對解決污染的方法也付之闕如。

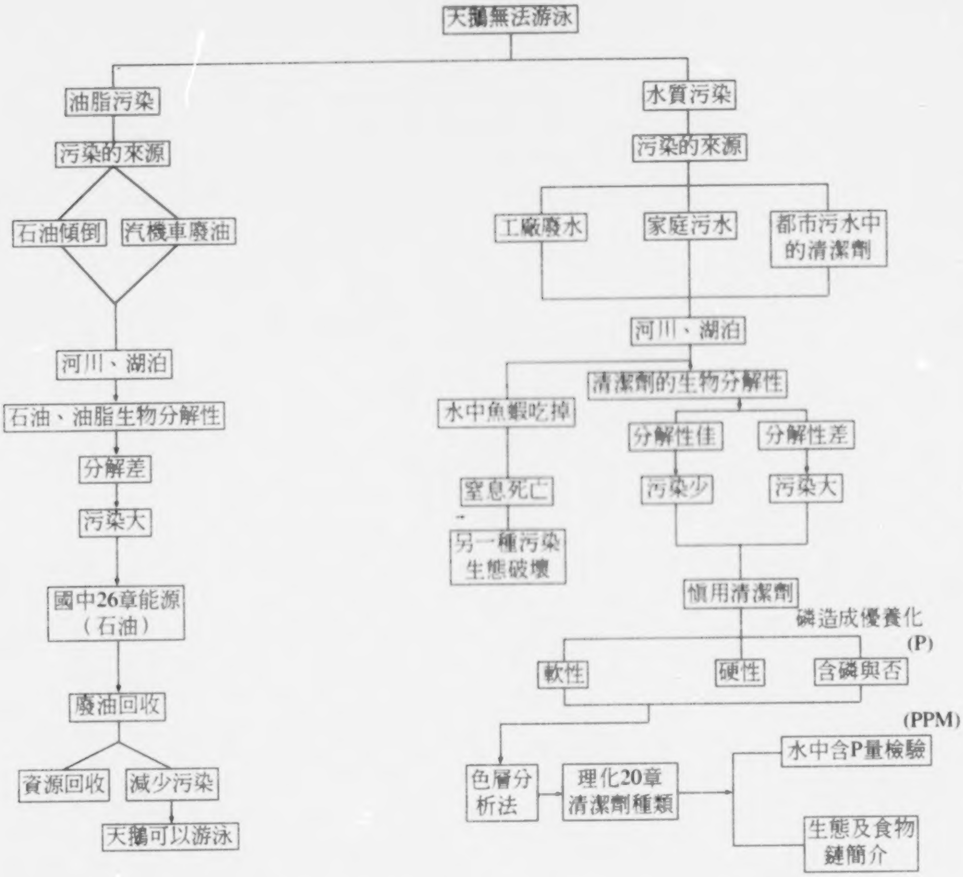
故爲階層二


天鵝無法游泳
天鵝的油脂被溶解
水中的污染問題
家庭廢水
水源污染
清潔劑
化糞污水
垃圾污染
工廠廢工
有分解性佳
無分解性差
垃圾分類
污水處理
污染少
污染多
環保問題
清潔劑的選擇
含磷洗衣粉
無磷洗衣粉
國中第四冊清潔劑

此ISM圖指出天鵝無法游泳的原因爲天鵝羽毛上的油脂被溶解，而污染源爲家庭及工廠所排放的廢水。這些廢水中含有清潔劑等化學物質會造成生態環境的破壞。因此在家庭方面需重視清潔劑使用上的選擇工廠方面需做好污水處理等工作。圖中已認出造成天鵝無法游泳一個以上的可能性原因和見解。

故爲階層三

BEST COPY AVAILABLE


天鵝無法游泳
油脂污染
水質污染
污染的來源
石油傾倒
汽機車廢油
河川、湖泊
石油、油脂生物分解性
分解差
污染大
國中26章能源（石油）
廢油回收
資源回收
減少污染
天鵝可以游泳
污染的來源
工廠廢水
家庭污水
都市污水中的清潔劑
河川、湖泊
清潔劑的生物分解性
水中魚蝦吃掉
窒息死亡
另一種污染生態破壞
分解性佳
分解性差
污染少
污染大
慎用清潔劑
磷造成優養化
(P)
軟性
硬性
含磷與否
(PPM)
色層分析法
理化20章清潔劑種類
水中含P量檢驗
生態及食物鏈簡介

此ISM圖以概括化定義說明了造成污染的途徑，清潔劑的成份與污染的關係，並提出解決之道。故爲階層四

STS主題的開放性思考之提昇：「清潔劑」

王澄霞・蔡曉信

國立台灣師範大學化學系

摘　要

要使STS的學習成功，教師應扮演著中心角色。因此提昇教師對STS主題的開放性思考是非常重要的。

參加國立臺灣師範大學化學系舉辦的暑期進修班之在職教師，在課程中安排教導使用解析結構法(ISM)來提昇他們對STS主題「清潔劑」的開放性思考。教師們針對STS主題分別用敘述式及ISM圖來表達他們的看法。本研究使用McDaniel的五個思考階層來評量教師之認知複雜度。評量結果顯示ISM法能提昇教師對真實生活中之STS主題的看法。

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Visualizing Mathematics under Limitation

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ABSTRACT

Illustration is an important part of mathematical experiment. In order to draw a meaningful and precise mathematical picture, the learner is led to active investigation of related properties of the problem. Mathematical visualization has become a reality with the assistance of the high-tech equipment. Mathematical illustration, however, may take place even under the conditions of limited computing resources. This paper discusses 10 mathematical visualization projects which are suitable for a laboratory equipped only with a personal computer and the software "Derive".

1. enveloping curves
2. reflections inside an ellipse
3. reflections inside a square
4. the intersection of two cylinders
5. the formation of conic sections
6. the involute of a circle
7. chaotic behavior
8. nested hexagons
9. pole and polar
10. marks on a ruler

Key words: educational technology, mathematics learning

I. Mathematical Experiments

Mathematical experiment is based on the idea that active involvement enhances students' learning. Since mathematics is generally regarded as an "abstract" subject, applying experiments to the mathematics class requires some planning in the part of teacher.One practical route for bringing the experiments to bear on students' mathematical understanding, however, is to use computer graphics to manipulate mathematics. Visualizing mathematics is particularly useful in helping the students move from the concrete to the abstract level. The teacher must have ample preparations both in computer skill and in mathematical knowledge for such a class.

II. Implementation of Mathematical Pictures with Derive

The computer algebra system Derive is a power ful tool for doing mathematics on a personal computer. This software package requires very little computing power: it runs under an 8088 computer with 512K of memory. It is designed to let users manipulate mathematics symbolically on a display the same way as with paper and pencil. Graphics implementation, however, was never the primary goal of its design. Since this software understands algebraic expressions, one can draw with ease the graph of a usual one-variable function of the form $y=f(x)$, a parametric curve of the form $[x(t), y(t)]$, $t \in [a, b]$ or a 3-D surface of the form $z=f(x, y)$. Although these basic capabilities are of fundamental importance in mathematics visualization, mathematical experiments usually require far more advanced graphics features.

III. Line-Drawing Capabilities

Despite its limited graphics capabilities, it is still possible to explore all sorts of geometric phenomena with Derive. The rest of this paper discusses concrete activities that both the students and the teacher may perform with the limited computing resource of having Derive as the sole software for mathematics experiment. Such a hypothetical computing environment could exist in schools with constrained computing facilities. The crucial idea is this: exploit what can be shown with pictures consisting of line segments only.

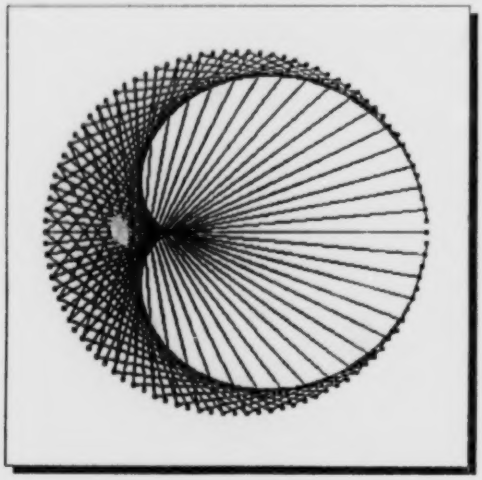
Ruler and compasses were regarded as the universal instruments of geometric constructions. What can be drawn with them are, by definition, all the constructions of the plane Euclidean geometry. As was shown in the work of Smogorzhevskii (1961), the investigation of constructions carried out by means of a ruler alone forms a host of stimulating exercises for students and scholars alike. The motivation for this work was very much influenced by this spirit of ruler-only construction. We are excited to report that what may have appeared as a serious handicap turns out to be an exciting pedagogical investigation.

IV. Fundamental Principle of Line-Drawing

Suppose that we are to draw a large number of line segments; lines, for example, connecting $(\cos t_k, \sin t_k)$ with $(\cos 2t_k, \sin 2t_k)$ as t_k ranges uniformly over the interval $[0, 2\pi]$. What would the appropriate Derive instruction be in order to accomplish this construction? The answer is:

```
VECTOR([[cos(t), sin(t)], [cos(2t), sin(2t)]], t, 0, 2pi, pi/50)
```

After the appro(X) command is applied to this one-line expression, a large numerical matrix is created. When the (P)lot command is applied to the this numerical matrix, the following appears:



In general an expression like

```
VECTOR([[a, b], [c, d]], t, h, k, s)
```

shall prepare us to draw many lines, the end-points (a, b), (c, d) of each depending on a parameter t, which varies over the interval $[h, k]$ with step-size s. To speed the pace of picture-displaying, the command appro (X), instead of (S)implifly, is applied to the above expression. This generates a matrix recording the numerical coordinates of the endpoints of the line segments. Before the final step of plotting, the user is urged to check to see that under the Options-State-Mode menu the option Connected is selected. If the class is equipped with a color display and wishes to see all line segments appearing in the same color, be sure that the option No is correctly switched under Options-Color-Auto. Also, one may inspect the menu under Options-Color-Plot to see if he Axes and the Cross are set to have the same color as the background; sometimes it's desirable to hide them entirely. If satisfied with all these settings, then just apply the (P)lot command and enjoy the picture.

Exploring line-drawing capabilities is a worthwhile effort as shown in this example: it is short, it is elegant and it requires thinking.

V. Overhanging of a Deck of Cards

A mathematical experiment may take many forms. The simplest ones challenge the students to draw a meaningful and precise mathematical illustration. Consider the following problem of recreational mathematics.

Given a deck of 52 playing cards with the first placed so that its end is flush with the table edge, find the maximal amount of overhanging achieved.

In this problem the thickness of the playing cards is irrelevant. An illustration of the situation could be judged meaningful if the relative position of the cards is shown. One could simply draw 52 line segments of equal length representing the sideview of the deck of cards. In order to make the drawing precise, one must devote more attention to analyzing the situation, somewhat along the following line of thinking.

If one playing card is placed on another, the greatest offset is obtained by having the center of gravity of the top card fall directly above the end of the lower card. These two cards, resting on the third, have maximum offset when their combined center of gravity is above the third card's edge. Continuing this manner, one finds that the top card projects half of a card's length. The second projects 1/4, the third 1/6 and so on.

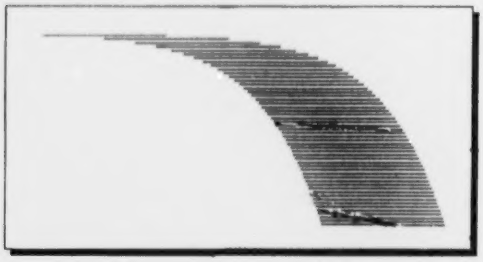
Having the situation thus thoroughly analyzed, the actual implementation with Derive could be as short as the next three lines:

```
a:= SUM(1/k, k, 1, n)

b:= a+2

VECTOR([[a, -n/10], [b, -n/10]], n, 0, 51)
```

A drawing, both meaningful and precise, now appears:



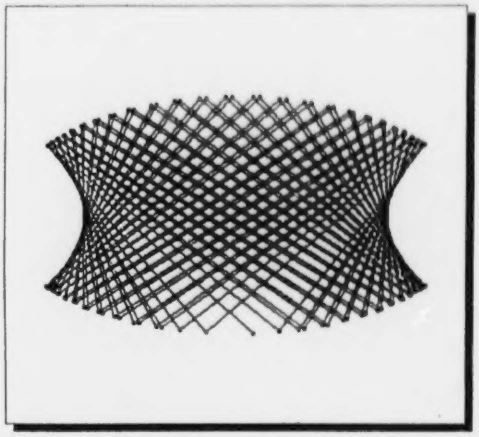
Since the sum of the series

1/2+1/4+1/6+...+=1/104
is approximately 2.25901, one sees that the maximum overhanging is slightly more than $2\frac{1}{4}$ card lengths.

What comes to the mind upon seeing this picture? It is natural to ask: as the number of cards increases, will the overhanging be greater than any pre-assigned length? A skillful teacher could, as in this situation, further ask the student to spell out the notion of convergence and divergence of an infinite series. It would appear to the learner that such abstract notions really arise from concrete problems.

VI. Reflections Inside an Ellipse

Imagine that a light ray, emitted in the interior of an ellipse, bounces back and forth when it hits the boundary, which is assumed to be made of perfectly reflective material. Can we theoretically predict the paths of the ensuing reflections? It turns out that two interesting patterns emerge. They correspond to the cases when the foci lie on either the same side or different sides of the initial path. If they don't, lie on the same side, then the reflected rays shall envelop a pair of hyperbolas. On the other hand, if the foci do lie on the same side of the initial path, then the reflected rays shall envelop another ellipse.



"Reflections inside an ellipse."

"The light beam passes from the point 1 to 11 and then to 111 on the ellipse"

"with the equation x^2/a^2+y^2/b^2=1."

```
a: =5

b:= 3
```

"The matrix m, which is used for plotting, changes from"

"m=[1, 11] to m=[11, 111] after each iteration."

```
11:= ELEMENT (m, 2)

1:= ELEMENT (m, 1)
```

"We assume the relation 11=[xx, yy]."

```
xx:= ELEMENT (11, 1)

yy:= ELEMENT (11, 2)
```

"The vector u points in the direction from 11 towards 1."

```
u:= 11-1
```

"The vector v gives the direction of the light beam

```
from 11 towards 111."

    v:= u−2×(u.n)×n/(n.n)

    "The light beam will reach 11 after time t"

    111: =11+t×v

    "We are assuming the vector v=[vx, vy]."

    vx:= ELEMENT ( v, 1)

    vy:= ELEMENT (v, 2)

    t:= -2×(b^2×vx×xx+a^2×yy×vy)/(b^2×vx^2+a^2
      ×vy^2)

    "n is the normal direction at the point 11."

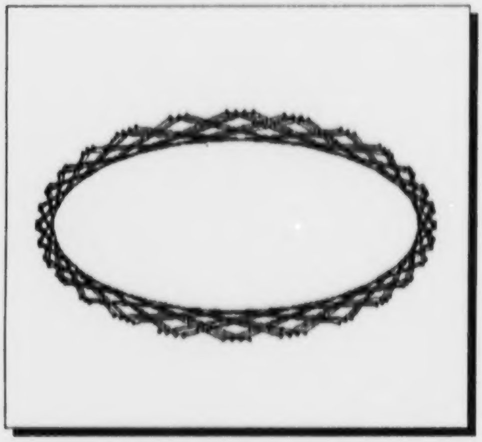
    n:= [-b×xx/a, -a×yy/b]

    NEXT(m):= [11, 111]

    "Apply approX command to the next line and
then plot."

    ITERATES (NEXT(m), m, [[a×COS(-1.5),
b×SIN(-1.5)], [a×COS(2.5), b×SIN(2.5)]], 100)

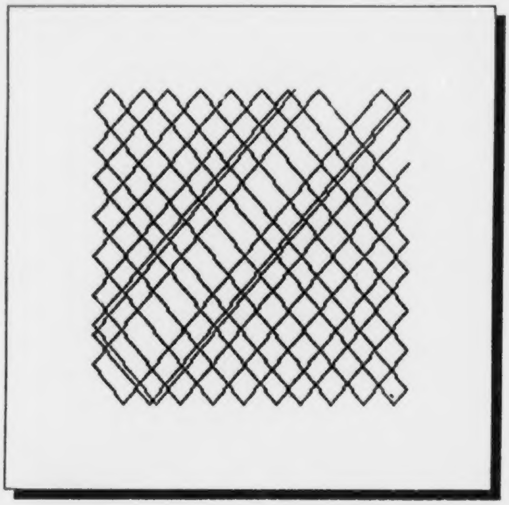
    "Change the initial parameter from 2.5 to 3.5 to
see what happens."
```



Illustrations like these cannot be found in mathematical texts published a generation ago. Experiments of this sort became possible only with the assistance of a computer.

VII. Reflections Inside a Rectangle

If a beam of light is trapped inside a square, the reflections sweep out a dense portion of a rectangle if the slope of the initial ray is irrational, otherwise they form a closed orbit. This phenomenon is simulated in this display:



```
    xx:= FLOOR (x+1)

    yy:= FLOOR (y+1)

    x:= ELEMENT (v, 1)

    y:= ELEMENT (v, 2)

    F(t):= 1−ABS (t−2×FLOOR(t/2)−1)

    s:=40

    N(v):= IF (yy−y>a×(xx−x), [xx, a×xx], [yy/a,yy])

    a:= 1.23456

    w:= ITERATES (N(v), v, [1, a] ,s)

    VECTOR (VECTOR(F(ELEMENT(w, i, j)), j,
1, 2), i, 1, s)
```

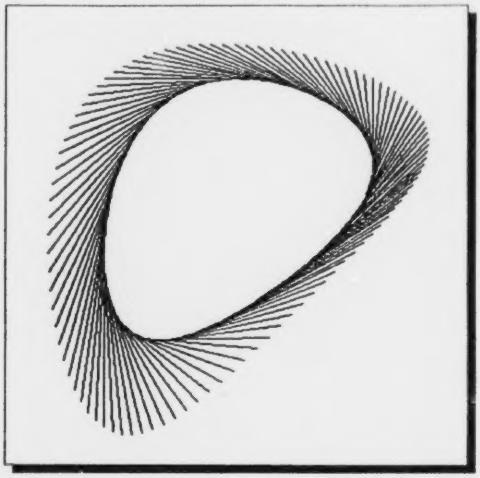
Here the slope *a* was set to be 1.23456. In performing an experiment like this we have to face the

reality imposed by the discrete nature of the computer display that no straight line can have a truly irrational slope!

VIII. Velocity Vectors

The geometric interpretation of the derivative of a function is that of the velocity. The line segment joining a point $[x(t), y(t)]$ of a smooth plane curve to the point $[x(t)+x'(t), y(t)+y'(t)]$ represents the velocity at a single point. When a large number of points of the curve are chosen and the corresponding velocity vectors are drawn, we get a better picture of the variation of the velocity. With Derive the procedure of drawing such a velocity vector field is especially simple, as shown in the following example with

$$x = \cos t\,,\ y = \frac{3\sin t + \cos t}{3 + \cos t}\,,\ t \in [\,0, 2\pi\,]$$



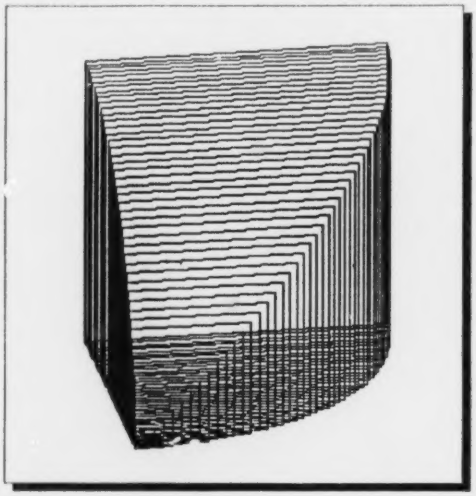
VECTOR([[x,y],[x+DIF(x,t),y+DIF(y,t)]],t,0, 2×pi, pi/50)

x:= COS(t)

y:= (3×SIN(t)+COS(t))/(3+COS(t))

IX. Intersection of Cylinders

The following region is considered in almost every calculus text: the intersection of the cylinders $x^2+y^2=1$ and $x^2+z^2=1$. The built-in graphics capability of most mathematical software packages does not allow the user to plot this region with ease. The appearance of one-quarter of the intersection is shown in the next figure. This unsophistcated 3-D illustration is based on standard topics like linear projection and spherical coordinates, found in most freshman calculus courses.



m:=[[COS(t), -SIN(t)×COS(s)], [SIN(t), COS(t)×COS(s)], [0, SIN(s)]]

s:= 1.2

t:= 1.4

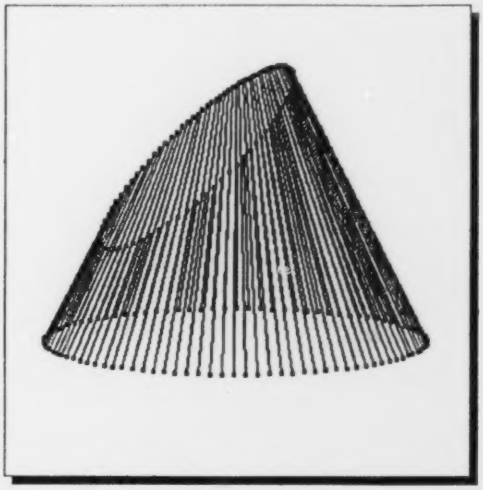
p:= [[COS(u),SIN(u),0],[COS(u),0,0],[COS(u), 0,SIN(u)],[COS(u),SIN(u),SIN(u)],[COS(u),SIN(u), 0]]

VECTOR(p.m, u, 0, pi/2, pi/100)

It is the discovery that certain cross-sections of the solid are comprised entirely of squares that makes the procedure so concise. Here the matrix *m* projects a point in R^3 linearly into the screen. The parameter *t* may be regarded as the longitude and *s* the latitude.

X. The Ellipse as a Conic Section

The term "conic section" refers to the three types of the most important curves studied in analytic geometry: the ellipse, the hyperbola and the parabola. Why are they called "conic sections"? The student probably has seen an actual model of a cone with various plane sections, or perhaps even has touched it, sometime in his past experience, in a well-equipped mathematical laboratory. How is such experience related to the algebraic expressions given in almost all textbooks of analytic geometry and calculus? To most students the geometric model and the algebraic symbols are two completely independent notions. If, however, we challenge them with the problem of reconstructing the conic sections with a computer, they are naturally lured into thinking of the curves in terms of the algebraic expression, since that is the only aspect a computer loaded with Derive is able to understand.



```
m:= [[COS(t), -SIN(t)×COS(s)], [SIN(t),
COS(t)×COS(s)], [0, SIN(s)]]

x:= COS(u)

y:= SIN(u)

z:= 0

q:= 4/(5×(COS(u)+2))

x1:= q×COS(u)

y1:= q×SIN(u)

z1:= x1+1.2

p:= [[x, y, z], [x1, y1. z1]]

VECTOR(p.m, u, 0, 2×pi, pi/50)

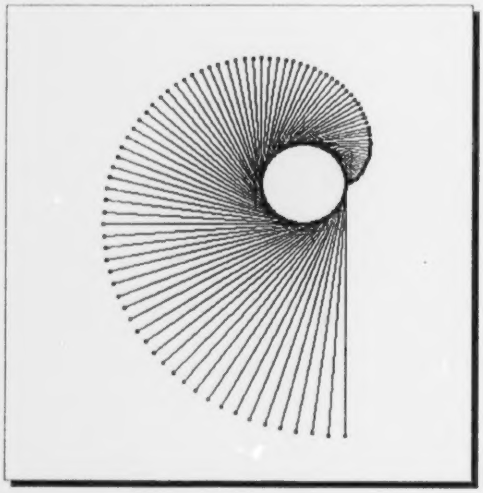
s:= 1.4

t:= 0.7
```

In this example computer graphics function as visual aids to the mathematics. We have to admit that the display on the screen may not convey as much information as a real geometric model. However, the process of creating such a graphic image does possess high educational value.

XI. Formation of the Involute

An involute of a curve is the path of a point of a string tautly unwound from the curve. The following figure, illustrating the formation of the involute, consists of line segments joining points of the unit circle to the corresponding points of the involute.



```
x:= COS(t)

y:= SIN(t)

p:= [[x, y], [x+y×t, y−x×t]]

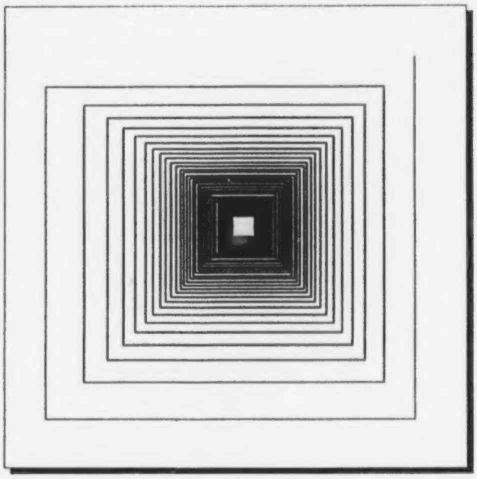
VECTOR(p, t, 0, 2×pi, pi/50)
```

XII. Chaotic Behavior

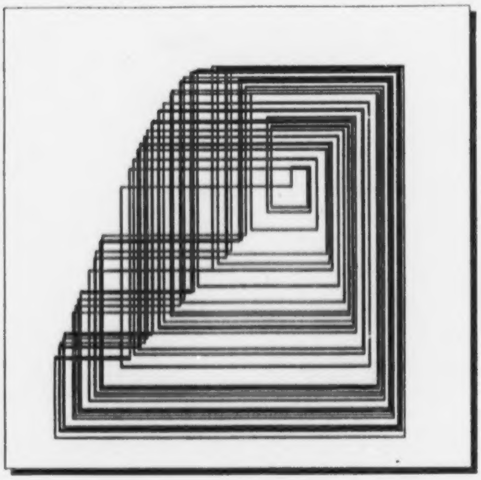
Take a point at random, say $z=1$, and start iterating the function

$f(x)=\cos(mx)$.

What does the orbit $\{f^k(z): k\geq 1\}$ look like? In the two figures below the line segments joining (z, z) with $(z, f(z))$ with $(f(z), f(z))$ with $(f(z), f(f(z)))$... are drawn. When $m=1.3$, the orbit is seen to converge.



When $m=2.5$ the orbit is seen to form a dense subset of an interval.



```
N(m):= [[g, g], [g, h], [h, h]]

h:= COS (k×ELEMENT (m, 2, 2))

g:= COS(k×ELEMENT(m, 1, 1))

k:= 2.4

k:= 1.9

ITERATES(N(m), m, [[1, 1], [1, COS(k)], [COS(k), COS(k)]], 100)

k:=2.1

k:=0.8

k:=1.3
```

Are these two cases the only possibilities that could happen to an orbit? For what values of m will the orbit belong to the same case? Is there a value for the parameter so that the orbit consists of a finite set of points? These are some of the questions that strike the learner upon seeing the above example.

In 1985, H. Kocak wrote the somewhat unusual book "Differential and Difference Equations through Computer Experiments." This work served both as a manual to the computer program "PHASER" as well as an illustrated guide to the wonderful world of experimental and theoretical dynamics. The idea behind the chaotic behavor drawing described above was borrowed from Kocak's chapter on difference equations (Kocak, 1986: 171-191).

XIII. Nested Hexagons

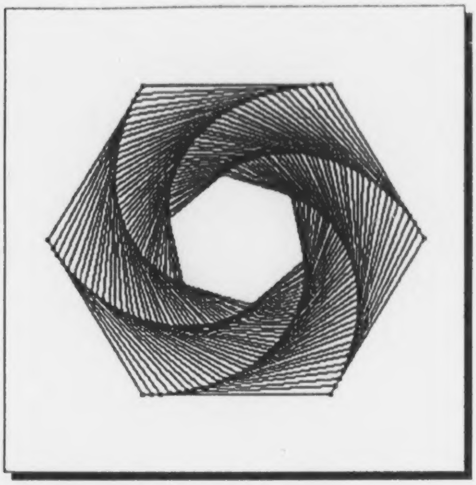
Divide each side of a hexagon P into the ratio $s/t=1/20$, proceeding cyclically counterclockwise (Davis, 1979). The points of division form the vertices of a new hexagon $\sigma(P)$. When the transformation σ is iterated , we obtain:

```
a:= VECTOR([COS(2×pi×k/6), SIN(2×pi×k/6)], k, 0, 6)

t:= 0.05

f:= VECTOR((1-t)×ELEMENT(m, i)+t×ELEMENT(m, i+1), i, 1, 6)

N(m):= APPEND(f, [(1–t)×ELEMENT(m,
```



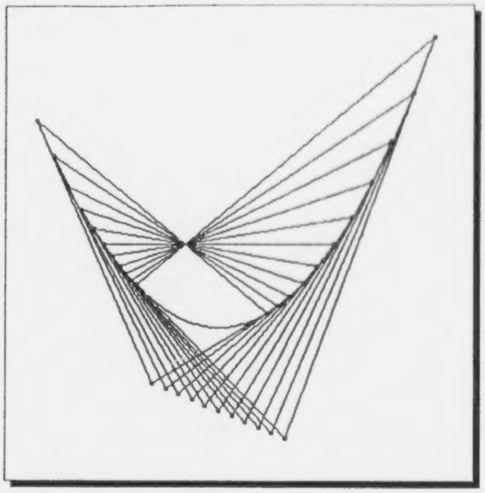
1)+t×ELEMENT(m,2)])

"Apply the command approX to the next expression and plot"

ITERATES(N(m), m, a, 40)

Don't we all wish that every mathematical picture possessed aesthetic value as high as this one?

XIV. Pole and Polar



Statements like:
"The poles of concurrent lines are colinear;"
"The polars of colinear points are concurrent,"

remind us that pole and polar are in harmony. Experimenting with figures like this reminds us that symbols and pictures are also in harmony. The interested readers may consult the highly inspirational work of Wells (1991).

"Let's consider the parabola given by the parametric equation."

$[t, t^2/4]$

"Suppose that [u, v] is some point in the plane"

"and [x, y]–[u, v] is tangent to the parabola at [x, y]."

v–x^2/4=x×(u–x)/2

"Solving x from the above equations:"

x=SQRT(u^2–4×v)+u

x=u–SQRT(u^2–4×v)

"Therefore [x1, y1] and [x2, y2] are points of intersection of the"

"tangents from [u, v] to the parabola."

x1:= SQRT(u^2–4×v)+u

x2:= u–SQRT(u^2–4×v)

"The following m consists of the coordinates of the triangle with vertices"

"[u, v], [x1, y1], [x2, y2]"

m:= [[u, v], [x1, y1], [x2, y2], [u, v]]

"To plot the triangles, just apply the approX command to the following"

"expression."

VECTOR(m, u, -2, 2, 4/10)

"here u runs over the interval [-2, 2] with step=4/10"

v:= -(u+2)/2–2

y1:= x1^2/4

```
y2:= x2^2/4
```

These steps were in our mind whtn designing this illustration:

(1) Fix a parabola

$$P: y = \frac{x^2}{4}.$$

(2) Fix a straight line

$$L: 2y+x+6=0.$$

(3) For each point (x, y) of L find the points (x_1, y_1), (x_2, y_2) of P so that the line segments $(x, y)-(x_1, y_1)$ and $(x, y)-(x_2, y_2)$ are tangent to P.

(4) Draw the triangles $(x, y)-(x_1, y_1)-(x_2, y_2)$ as (x, y) ranges over some portion of L.

For the sake of clarity, we have added a parabola, a curve not formed by line segments, in this illustration.

XV. Marks on a Ruler

Consider the pattern formed by the marks on a one-inch segment of an old English ruler. It is obtained from successive binary divisions of the inch into halves, quarters, eighths, and sixteenths and so on. The pattern is encountered frequently in mathematical puzzles, the Chinese Rings and the Tower of Hanoi being two well-known examples (Gardner, 1967). The procedure for drawing the pattern follows the obvious steps:

(1) divide an interval into two subintervals of equal length and place a line of appropriate size in the middle;

(2) repeat the same steps for each of the subintervals.

In terms of Derive, the analysis amounts to the commands:

```
M(x, y):= (x+y)/2

P(x, y, n):= [(M(x, y), n], [M(x, y), 0]]

A(b, c):= APPEND(b, c)

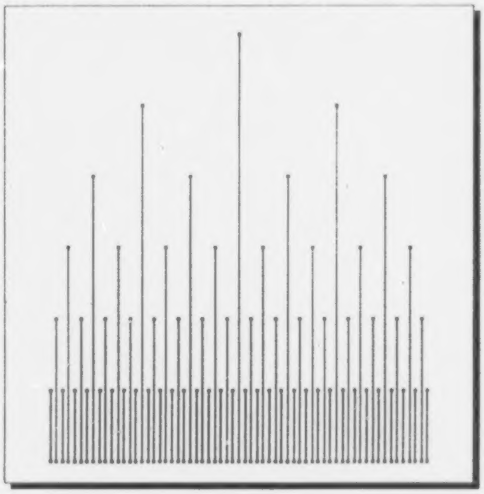
Q(x, y, n):=

L(x, y, n):= Q(x, M(x, y), n)

R(x, y, n):= Q(M(x, y), y, n)

Q(x, y, n):= IF(n>0, A(A([P(x, y, n)], L(x, y, n-1)),
R(x, y, n-1)), [])

Q(-1, 1, 4)
```



This example adopts a recursive procedure in producing the figure. It points out the possibilities of exploring recursive curves with Derive.

References

Davis, P. J. (1979). *Circulant matrices.* New York: John Wiley and Sons.

Gardner, M. (1967). *The scientific American book of mathematical puzzles and diversions.* Prentice Hall, Englewood Cliffs.

Kocak, H. (1986). *Differential and difference equations through computer experiments.* New York: Springer.

Smogorzhevskii, A.S. (1961). *The ruler in geometrical constructions.* New York: Blaisdell.

Wells, D. (1991). *The penguin dictionary of curious and interesting geometry.* London: Penguin.

Visualizing Mathematics under Limitation

克難式的數學作圖

全任重

國立清華大學數學系

摘　要

作圖是一項數學實驗裡的重要活動，它能促使學習者主動的去探討和解決相關的種種數學問題。數學的視覺化是當前數學作圖的最理想的表達方法，然而當計算設備尚未充足時，數學作圖亦能巧妙的進行。假設數學實驗的設備只具有個人電腦和軟體Derive，本文探討能夠在如此克難之環境下進行的十項數學實驗題材：

一、包絡線
二、橢圓形裡的反射
三、正方形裡的反射
四、兩圓柱體之公共部份
五、圓錐曲線的形成
六、圓的漸伸線
七、混沌現象
八、六角形套
九、極點和極
十、尺上的標記

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A Correlation of Creative Thinking Ability and Science Ability among Mathematics/Science Gifted Senior-High-School Students

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ABSTRACT

This study was to examine the creative thinking ability and science achievement of the 12th grade science/mathematics gifted in Taiwan, Republic of China. Torrance Tests of Creative Thinking (TTCT) Abbreviated Form and three different achievement tests were administered to 1051 12th grade students (474 science/mathematics gifted students and 577 average students) from 12 senior high schools in Taiwan in Nov. 1991 and Mar. 1992, respectively. TTCT is divided into three parts, Fluency, Flexibility, and Originality. The achievement tests were in Physics, Chemistry, and Mathematics. Results were analyzed by T-test and Pearson correlation. It showed the gifted students were superior to the average students in all three TTCT and all three achievement test scores, in which all reached the 0.05 significant difference level. Furthermore, the gifted male students got higher scores than gifted female students in three of the TTCT scores and all three achievement scores where only the Fluency, Originality, Mathematics, and Physics reached the 0.05 significant difference level. Moreover, there were no significant differences between the average male students and the average female students on any of the TTCT scores and three achievement scores. There were statistically significant relationships among gifted students' TTCT and the three achievement tests.

Key words: Torrance Tests of Creative Thinking, gifted student, achievement test

I. Introduction

This tracing study of gifted high school students in Taiwan R.O.C., started in 1989, serves as a guide for education of the gifted (Wey, 1990, 1991, 1992). This is the third year of the gifted-high-school-students tracing project, focusing on gifted 12th-grade students' creative thinking ability and their achievement in chemistry, physics, and mathematics. The Torrance Tests of Creative Thinking (TTCT) were originally developed by E. P. Torrance in the 1960's as a primary measure of creative thinking ability and have been widely used in several countries (Lin, 1985). The TTCT-Abbreviated Form (1984) was modified from TTCT, simplifying the scoring procedures and test content, and including affective domain. The TTCT contains three parts: Fluency, Flexibility, and Originality. The Felker and Treffinger (1971) study indicated the high self-concept pupils scored significantly better than low self-concept pupils on TTCT. Several studies indicated gifted students have higher self-concept than average students. Moreover, several studies show that self-concept has significant correlation with academic ability (Colangelo & Pfleger, 1978). Therefore, this study is trying to examine how gifted students perform on TTCT and three science achievement tests in comparison with average students.

The 12 senior high schools involved in this study have science/mathematics specialized classes gifted students. Only Chienkuo and NTNU Affiliated senior high schools have two classes of gifted students receiving a science/mathematics enrichment program, and another school has only one such class. In this study, we also randomly picked one normal class of students from each school as our control group.

II. Purpose

The purpose of this study was to investigate the difference between the gifted 12th grade students and average 12th grade students in their creative thinking ability and science achievement. It was hypothesised that related to the TTCT and three science achievement tests the preferences of (1). gifted students would be different from those of average students; (2). males would be different from those of females; (3). gifted males would be different from gifted females; (4). average males would be different from those of average females. Moreover, any relationship among the TTCT scores and three science achievement test scores were also examined.

III. Method

The Torrance Tests of Creative Thinking (TTCT) was originally developed by the E. P. Torrance in the 1960's as a primary measure of creative thinking ability and has been widely used in several countries. The TTCT-Abbreviated Form (1984) was modified from TTCT by simplfying the scoring procedures and test content, and including affective domain. The TTCT contains three parts: Fluency, Flexibility, and Originality. The cross-coder reliabilities of TTCT Fluency, Flexibility, and Originality are 0.992, 0.984, and 0.968, respectively. The factor analyses of this TTCT Fluency, Flexibility, and Originality are 0.85, 0.89, and 0.87. The three science achievement tests were developed by a group of science professors and science educators. The TTCT test and three science achievement tests were administered to 1051 12th grade students: 474 science/mathematics-gifted students and 577 average students. After scores were given by professional educators, they started to analyze them by t test and Pearson correlation.

IV. Results

Table 1 and 8 shows the performance of gifted and average students on three parts of TTCT and three different achievement test scores. It indicates that the gifted students got higher scores than average students in Fluency, Flexibility, and Originality. The t values of Fluency, Flexibility, and Originality were 9.08, 8.11, and 9.18, which all reached 0.05 significant difference level. This also was supported by the comparisons of individual schools' gifted students' and average students' three achievement scores in Table 5, 6, and 7. In general, gifted students got higher scores on Fluency, Flexibility, and Originality than average students. The only exception is the Originality part, in which Kaohsiung senior-high-school gifted students got lower scores than average students. This indicated that the gifted students got higher scores than average students in Mathematics, Physics, and Chemistry achievement tests. The t value of Mathematics, Physics, and Chemistry achievement scores were 13.10, 15.20, and 17.51, which all reached the 0.05 significant difference level. This also was supported by the comparisons of individual schools' gifted students' and average students' three achievement scores in Table 12, 13, and 14. In general, gifted students got higher scores on Mathematics, Physics, and Chemistry than

Table 1. Tests of Significance of Differences of Mean Fluency, Flexibility, and Originality Scores for Gifted Students and Average Students

Score and Group		Number	Mean	Standard Deviation	t-value	Probability
Fluency	G	474	105.9	20.44	9.08	<.001
	A	577	95.1	18.28		
Flexibility	G	474	105.4	19.59	8.11	<.001
	A	577	95.7	19.15		
Originality	G	474	106.4	20.61	9.18	<.001
	A	577	95.5	17.98		

G : Gifted; A : Average

Table 2. **Tests of Significance of Differences of Mean Fluency, Flexibility, and Originality Scores for Gifted Male and Female Students**

Score and Group		Number	Mean	Standard Deviation	t-value	Probability
Fluency	M	684	100.9	21.37	1.92	<.06
	F	367	98.4	17.11		
Flexibility	M	684	99.9	20.81	-0.27	<.79
	F	367	100.3	18.31		
Originality	M	684	101.44	20.61	2.31	<.021
	F	367	98.46	17.98		

M : Male; F : Female

Table 3. **Tests of Significance of Differences of Mean Fluency, Flexibility, and Originality Scores for Gifted Male and Female Among the Gifted**

Score and Group		Number	Mean	Standard Deviation	t-value	Probability
Fluency	M	329	107.2	21.73	1.99	<.05
	F	145	103.2	16.88		
Flexibility	M	32	105.6	20.37	0.30	<.77
	F	145	105.1	17.77		
Originality	M	329	107.74	21.63	2.08	<.04
	F	145	103.4	17.80		

M : Male; F : Female

Table 4. **Tests of Significance of Differences of Mean Fluency, Flexibility, and Originality Scores for Gifted Male and Female Among the Average**

Score and Group		Number	Mean	Standard Deviation	t-value	Probability
Fluency	M	355	95.0	12.29	-.17	<.87
	F	222	95.3	16.57		
Flexibility	M	355	94.7	19.85	-1.55	<.13
	F	222	97.2	18.03		
Originality	M	355	95.6	18.67	.29	<.78
	F	222	95.2	16.85		

M : Male; F : Female

Table 5. Tests of Significance of Differences of Mean Fluency Scores for 12 Individual Schools' Gifted and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	88	107.8	22.42	3.55	<.001
	A	54	95.8	17.51		
NTNU Affiliated	G	70	97.8	17.37	2.1	<.038
	A	45	91.2	16.11		
Taipei First Girls	G	41	102.5	14.85	1.90	<.060
	A	50	96.7	13.90		
Wulin	G	34	108.8	22.61	0.82	<.418
	A	47	87.8	16.48		
Hsinchu	G	36	103.0	18.78	3.84	<.000
	A	47	87.8	16.48		
Taichung	G	30	128.2	21.79	7.22	<.000
	A	42	93.9	16.81		
Taichung Girls	G	33	112.3	20.24	4.22	<.000
	A	53	93.6	19.65		
Chiayi	G	28	110.1	21.24	4.27	<.000
	A	48	89.9	17.42		
Chiayi Girls	G	24	93.5	14.18	0.29	<.770
	A	53	92.4	16.58		
Tainan	G	35	105.9	19.70	1.58	<.118
	A	46	99.3	17.05		
Tainan Girls	G	30	105.8	12.79	2.16	<.035
	A	45	99.2	13.43		
Kaohsiung	G	25	101.3	16.40	0.87	<.389
	A	44	97.3	20.84		

G : Gifted; A : Average

average students.

Table 2 and 9 were the results of comparing all male and female students' TTCT and three different achievement test scores. It showed that males got higher scores on Fluency and Originality, and Mathematics and Physics than females, and females got higher scores on Flexibility and Chemistry than males. It also indicated that the t value of Fluency, Flexibility, and Originality were 1.92, -0.27, and 0.021, which did not reach 0.05 significant difference level. It also indicated that the t value of Mathematics, Physics, and Chemistry achievement scores were 5.73, 6.70, and -.065, of which only Mathematics and Physics reached the 0.05 significant difference level.

The results of comparing the gifted male and female students' TTCT scores are in Table 3. The gifted male students got higher Fluency, Flexibility, and Originality scores than gifted female students. The t values of Fluency, Flexibility, and Originality were 1.99, 0.30, and 2.08, of which were only Fluency, and Originality reached the 0.05 significant difference level. Comparing the gifted male and gifted female students' three achievement scores indicated that gifted male students got higher Mathematics, Physics, and Chemistry scores than gifted female students (Table 10). The t values of Mathematics, Phy-

Table 6. Tests of Significance of Differences of Mean Flexiblity Scores for 12 Individual Schools' Gifted and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	88	104.3	20.40	2.71	<.008
	A	54	95.4	17.81		
NTNU Affiliated	G	70	96.3	19.21	0.34	<.738
	A	45	95.1	18.16		
Taipei First Girls	G	41	105.4	16.81	1.66	<.101
	A	50	99.4	17.34		
Wulin	G	34	107.0	24.37	0.90	<.370
	A	47	102.2	23.76		
Hsinchu	G	36	106.2	17.92	3.67	<.000
	A	47	91.0	19.78		
Taichung	G	30	121.8	16.89	6.14	<.000
	A	42	95.5	19.21		
Taichung Girls	G	33	113.0	15.91	4.65	<.000
	A	53	95.4	18.89		
Chiayi	G	28	106.8	15.99	4.80	<.000
	A	48	88.4	16.38		
Chiayi Girls	G	24	96.7	18.45	0.71	<.484
	A	53	93.5	18.32		
Tainan	G	35	106.5	19.16	3.08	<.003
	A	46	94.0	16.79		
Tainan Girls	G	30	108.7	16.26	2.00	<.050
	A	45	101.2	15.42		
Kaohsiung	G	25	104.2	18.50	1.29	<.201
	A	44	97.5	24.26		

G : Gifted; A : Average

sics, and Chemistry were 3.67, 4.11, and 0.30, of which only Mathematics, and Physics reached the 0.05 significant difference level.

Table 4 and 11 were the results of comparing average male and female students' TTCT and three achievement test scores. The female students got higher scores on Fluency, Flexibility, and Chemistry than male students; and the male students got higher scores on Originality, Mathematics and Physics than female students. None of them reached the 0.05 signi-ficant difference level. The t values of Mathematics, Physics, and Chemistry were 3.84, 4.95, and -2.90, all of them reached the 0.05 significant difference level.

Tables 5, 6, and 7 compare gifted class students' and average class students Fluency score, Flexibility, and Originality scores within each individual school. Among the 12 senior high schools, gifted class students got higher scores in Fluency than average class students. There were seven schools reaching the 0.05 significant difference level: Chienkuo, NTNU Affiliated, Hsinchu, Taichung, Taichung Girls, Tainan Girls, and Chiayi Senior high school. Within each individual school, gifted class students got higher scores on Flexibility scores than average class students (Table 6). There are seven schools reaching the

Table 7. Tests of Significance of Differences of Mean Originality Scores for 12 Individual Schools' Gifted and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	88	109.2	23.73	2.99	<.003
	A	54	98.0	17.86		
NTNU Affiliated	G	70	100.2	16.01	3.14	<.003
	A	45	90.0	15.02		
Taipei First Girls	G	41	100.3	17.67	0.03	<.975
	A	50	100.2	17.72		
Wulin	G	34	106.5	20.28	0.73	<.470
	A	47	102.9	25.37		
Hsinchu	G	36	104.6	15.81	5.11	<.000
	A	47	87.1	14.96		
Taichung	G	30	126.3	22.42	7.06	<.000
	A	42	93.1	14.84		
Taichung Girls	G	33	114.3	20.77	6.59	<.000
	A	53	89.5	14.03		
Chiayi	G	28	112.5	20.39	3.61	<.001
	A	48	95.8	17.93		
Chiayi Girls	G	24	94.5	11.33	0.48	<.630
	A	53	93.0	14.96		
Tainan	G	35	105.5	23.74	1.95	<.055
	A	46	96.8	16.27		
Tainan Girls	G	30	106.5	15.48	2.17	<.034
	A	45	98.2	17.10		
Kaohsiung	G	25	97.9	15.07	-0.47	<.637
	A	44	99.9	21.08		

G : Gifted; A : Average

Table 8. Tests of Significance of Differences of Mean Mathematics, Physics and Chemistry Scores for Male and Female Students

Score	Group	Number	Mean	Standard Deviation	t-value	Probability
Mathematics	G	465	39.76	17.58	13.10	0.000
	A	541	26.31	14.99		
Physics	G	465	36.58	11.29	15.20	0.000
	A	541	26.60	9.53		
Chemistry	G	465	62.57	12.84	17.51	0.000
	A	541	48.36	12.81		

G : Gifted; A : Average

Table 9. Tests of Significance of Differences of Mean Mathematics, Physics and Chemistry Scores for Male and Female Students

Score	Group	Number	Mean	Standard Deviation	t-value	Probability
Mathematics	G	648	34.85	17.90	5.73	0.000
	A	358	28.32	16.12		
Physics	G	648	32.98	11.48	6.70	0.000
	A	358	28.00	10.87		
Chemistry	G	648	54.70	15.07	-0.65	0.515
	A	358	55.33	13.86		

G : Gifted; A : Average

Table 10. Tests of Significance of Differences of Mean Mathematics, Physics and Chemistry Scores for Male and Female Among the Gifted

Score	Group	Number	Mean	Standard Deviation	t-value	Probability
Mathematics	M	316	41.78	17.70	3.67	0.000
	F	149	35.46	16.57		
Physics	M	316	38.03	11.13	4.11	0.000
	F	149	33.50	11.05		
Chemistry	M	316	62.69	12.97	0.30	0.762
	F	149	62.30	12.61		

M : Male; F : Female

Table 11. Tests of Significance of Differences of Mean Mathematics, Physics and Chemistry Scores for Male and Female Among the Average

Score	Group	Number	Mean	Standard Deviation	t-value	Probability
Mathematics	M	332	28.25	15.45	3.84	0.000
	F	209	23.22	13.71		
Physics	M	332	28.17	9.60	4.95	0.000
	F	209	24.10	8.88		
Chemistry	M	332	47.10	12.84	-2.90	0.004
	F	209	50.36	12.53		

M : Male; F : Female

Table 12. Tests of Significance of Differences of Mean Mathematics Scores for 12 Individual Schools' Gifted Students and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	87	44.77	15.11	3.67	0.000
	A	54	35.00	15.75		
NTNU Affiliated	G	70	27.50	16.93	2.18	0.031
	A	48	21.10	13.48		
Taipei First Girls	G	40	37.83	16.33	2.67	0.004
	A	47	27.51	15.97		
Wulin	G	33	31.21	12.20	4.93	0.000
	A	48	18.13	11.39		
Hsinchu	G	37	38.65	14.23	6.72	0.000
	A	41	19.37	12.79		
Taichung	G	30	60.33	12.14	7.15	0.000
	A	40	38.73	12.79		
Taichung Girls	G	33	38.33	16.40	2.90	0.005
	A	52	29.17	12.64		
Chiayi	G	24	37.46	12.33	2.66	0.010
	A	46	28.00	14.97		
Chiayi Girls	G	28	28.46	16.06	4.54	0.000
	A	46	14.61	10.24		
Tainan	G	30	47.97	14.85	3.98	0.000
	A	41	33.71	14.99		
Tainan Girls	G	30	40.57	15.26	5.31	0.000
	A	44	24.30	11.12		
Kaohsiung	G	23	55.09	16.18	6.88	0.000
	A	34	25.88	15.41		

G : Gifted; A : Average

0.05 significant difference level: Chienkuo, Hsinchu, Taichung, Taichung Girls, Tainan, Tainan Girls, and Chiayi Senior high schools. Table 7 showed that except in Kaohsiung Senior High School, where average class students got higher scores than gifted class students, and Taipei First Girls Senior High School, which got almost the same scores, all of the other 10 schools' gifted class students got higher Originality scores than average class students. The Taipei First Girls Senior High Schools' gifted class students and average class students got similar means of 100.3 and 100.2, respectively. The t-values of comparing Kaohsiung Senior High Schools' gifted class students and average class students were negative 0.47. Seven schools reached the 0.05 significant difference level: Chienkuo, NTNU Affiliated, Hsinchu, Taichung, Taichung Girls, Tainan Girls, and Chiayi Senior High Schools.

Table 12, 13 and 14 compare gifted class students and average class students' Mathematics, Physics and Chemistry achievement scores within each individual school. Gifted class students got higher scores in Mathematics and Physics than average class students among the 12 schools. Ten schools' gifted class students reached the 0.05 significant difference level: Chienkuo, Taipei First Girls, Wulin, Taichung, Taichung Girls, Tainan, Tainan Girls, Kaohsiung, and Chiayi Girls Senior high schools. Except for the NTNU Affili-

Table 13. Tests of Significance of Differences of Mean Physics Scores for 12 Individual Schools' Gifted Students and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	87	36.37	9.96	3.18	0.002
	A	54	31.17	8.37		
NTNU Affiliated	G	70	38.44	11.58	2.79	0.006
	A	48	26.88	9.11		
Taipei First Girls	G	40	29.08	10.40	0.32	0.751
	A	47	28.36	10.40		
Wulin	G	33	34.36	9.50	5.94	0.000
	A	48	21.98	9.02		
Hsinchu	G	37	36.92	10.30	5.64	0.000
	A	41	24.66	8.88		
Taichung	G	30	43.44	12.94	4.86	0.000
	A	40	30.23	9.63		
Taichung Girls	G	33	32.09	9.66	4.21	0.000
	A	52	24.40	7.15		
Chiayi	G	24	43.17	11.17	6.30	0.000
	A	46	26.24	10.40		
Chiayi Girls	G	28	38.07	8.99	10.08	0.000
	A	46	18.35	7.62		
Tainan	G	30	40.87	11.45	5.17	0.000
	A	41	28.80	8.20		
Tainan Girls	G	30	41.57	9.39	7.71	0.000
	A	44	27.23	6.27		
Kaohsiung	G	23	42.57	10.23	3.63	0.001
	A	34	32.62	10.10		

G : Gifted; A : Average

ated and Taipei First Girl Senior high schools gifted class students, all of the other ten schools all reached the 0.05 significant difference level. Except for Taipei First Girl Senior High School's average class students, who got higher scores than gifted class students (58.55 and 53.81), all of the other 11 schools' gifted class students got higher Chemistry scores than average class students. It showed that all of the 11 schools reached the 0.05 significant difference level except Taipei First Girls Senior High School.

Table 15 correlates gifted students' TTCT scores and their three achievement scores. Gifted students' Mathematics achievement scores have significant correlation with TTCT Originality, Flexibility, and Fluency scores, which were 0.16, 0.14, and 0.16. Gifted students' Physics achievement scores have significant correlation with TTCT Originality, Flexibility, and Fluency scores, which were 0.12, 0.12, and 0.12. Gifted students' Chemistry achievement scores have significant correlation with TTCT Originality, Flexibility, and Fluency scores, which were 0.17, 0.13, and 0.13.

Table 16 correlates average students' TTCT scores and their three achievement scores. The results showed that only average students' Physics achievement scores have significant correlation with TTCT Originality, Flexibility, and Fluency scores, which were 0.12, 0.11, and 0.15.

Table 14. Tests of Significance of Differences of Mean Chemistry Scores for 12 Individual Schools' Gifted and Average Students

School	Group	Number	Mean	Standard Deviation	t-value	Probability
Chien Kuo	G	87	64.26	12.44	7.18	0.000
	A	54	48.28	13.50		
NTNU Affiliated	G	70	54.31	13.71	2.88	0.005
	A	48	47.54	10.60		
Taipei First Girls	G	40	53.81	10.92	1.80	0.076
	A	47	58.55	13.30		
Wulin	G	33	58.73	11.86	5.40	0.000
	A	48	45.02	10.77		
Hsinchu	G	37	63.24	11.66	10.70	0.000
	A	41	34.95	11.66		
Taichung	G	30	67.40	9.38	7.23	0.000
	A	40	51.50	8.89		
Taichung Girls	G	33	71.94	8.79	8.82	0.000
	A	52	49.40	12.89		
Chiayi	G	24	66.79	11.29	7.17	0.000
	A	46	46.43	11.26		
Chiayi Girls	G	28	60.04	12.68	3.66	0.000
	A	46	48.72	13.04		
Tainan	G	30	63.07	15.91	4.48	0.000
	A	41	47.37	13.54		
Tainan Girls	G	30	65.27	9.71	5.28	0.000
	A	44	53.20	9.62		
Kaohsiung	G	23	67.39	11.00	3.72	0.000
	A	34	54.79	13.48		

G : Gifted; A : Average

Table 15. Pearson Correlation Among Gifted Students' TTCT Scores and Their Three Achievement Scores

	Mathematics	Physics	Chemistry
Fluency	.1557**	.1165*	.1668**
Flexibility	.1363*	.1177*	.1274*
Originality	.1617**	.1226*	.1267*

N of cases : 443 1-tailed Signif : * -.01**-.001

Table 16. Pearson Correlation Among Average Students' TTCT Scores and Their Three Achievement Scores

	Mathematics	Physics	Chemistry
Fluency	.0077	.1178*	.0858
Flexibility	-0.192	.1104*	.0846
Originality	0.202**	.1447**	.0850

N of cases : 508 1-tailed Signif : * -.01**-.001

V. Discussion and Conclusion

The first research question dealt with gifted 12th grade and average 12th grade students' creative thinking ability and their science achievement. Results indicated that gifted students from 11 of 12 senior high schools got higher scores on all three Torrance Test (Fluency, Flexibility, and Originality) and three Achievement Tests (Mathematics, Physics, and Chemistry) except the Kaohsiung Senior High Schools' average class students, however, got higher scores on Originality than their gifted class students. The Felker and Treffinger (1971) study indicated the high self-concept pupils scored significantly greater than low self-concept pupils on TTCT. Several studies indicated that gifted students have higher self-concept than average students. Moreover, several studies of gifted students have indicated that self-concept has significant correlation with academic ability (Colangelo & Pfleger, 1978). This might help explain why gifted students got higher scores on TTCT and the three science achievement tests. Possible reasons for Kaohsiung Senior High School gifted students' Originality scores being lower than those of average students might be that students did not pay much attention on the tests, or their school did not centralize all gifted students in one class, so those students did not receive appropriate enrichment education. Another possible reason might be that the gifted students felt high stress at being designated as gifted students. This can be supported by Belcher and Parisi (1974), whose control group students scored significantly better than both (high and low) stress groups.

The second research question was to investigate the male and female students' creative thinking ability and science achievement. Results were that males got higher scores on Fluency, Originality, Mathematics, and Physics than females, and this also reached the significant difference level on Originality scores. The female students got higher scores on Flexibility and Chemistry than male students. There is still no consensus about whether male students always perform better on TTCT and science achievement than girls. Newland's (1981) study indicated females scored higher than male on TTCT. On the other hand, in Check (1969) found there is no difference between male and female students on their TTCT.

The third research question was to examine gifted students' creative thinking ability and science achievement. The gifted male students got higher scores on all of the three TTCT and science achievement tests than gifted female students, and especially in Fluency, Originality, Mathematics, and Physics, which reached the significant level.

The fourth research question was to deal with the average female students' and average male students' creative thinking ability and science achievement. The results show that the female students got higher scores on Fluency, Flexibility, and Chemistry than male students, but none of them reached the significant difference level. The average male students got higher scores on Originality, Mathematics, and Physics than female students, and both Mathematics and Physics reached significant difference levels.

The fifth research question was to examine the relationship among students' TTCT and three achievement scores. Statistically significant relationships were found between: gifted students' TTCT and three achievement scores; average students' Physics scores and TTCT scores. So far, no research literature has reported that TTCT has any correlation with students' achievement in any subject, so more research is highly recommended.

VI. Implications

There are several implications about how to educate gifted students.

The Taichung Senior High School gifted class students were highest on all three TTCT scores, and Mathematics and Physics scores among gifted and average class students at 12 senior high schools. Taichung Senior High School's methods might be worth investigation to give other schools a model for education of their gifted students.

Moreover, according to the Ristow's (1988) study, using direct instruction by brainstorming, product-improvement techniques, and verbal problem solving will improve the performance on TTCT. This might be good for us to try. Puranajoti's (1972) study found that creativity in girls was influenced to a greater extent by teacher behavior than was creativity in boys, which indicated that the method of educating gifted female students is especially important.

More research needs to be done on education of the students; ethnographic study is highly recommended.

References

Belcher, T. L. & Parisi, S. A. (1974). *Effects of test situation stress upon creativity test scores.* Paper presented at the Annual Meeting of the American Educational Research Association. (ERIC Document Reproduction Service No. ED093937).

Check, J. F. (1969). *An analysis of differences in creative*

ability between white and negro students, public and parochial, three different grade levels, and males and females, final report. (ERIC Document Reproduction Service No. ED. 031757).

Colangelo, N. & Pfleger, L. R. (1978). Academic self-concept of gifted high school students. *Roeper Review: A Journal on Gifted Child Education, 1*(1), 10-11.

Felker, D. W. & Treffinger, D. J. (1971). *Self concept, divergent thinking abilities, and attitudes about creativity and problem solving.* Paper presented at the American Educational Research Association Convention in New York. (ERIC Document Reproduction Service No. ED 047347).

Lin, H. T. & Pan, S. C. (1985). The first report of studying and developing new edition Torrance Creative Thinking Test. *Journal of Research Reports of National Taiwan Normal University Special Education, 1,* 313-318. (In Chinese)

Newland, G. A. (1981). Differences between left- and right-handers on a measure of creativity. *Perceptual and Motor Skills, 53*(3), 787-792.

Puranajoti, T. A. (1972). *A study of the relationship between the verbal interaction of elementary science teachers with their students and students' creativity.* (Ed. D Dissertation, University of Northern Colorado, 1992) (ERIC Document Reproduction Service No. ED 070591).

Ristow, R. S. (1988). The teaching of thinking skills: Does it improve creativity? *Gifted Child Today, 11*(2), 44-46.

Torrance, E. P. (1966). *Torrance Tests of Creative Thinking: Directions manual and scoring guide* (verbal test, form B). Princeton, N. J.: Personnel Press, Inc.

Torrance, E. P. & Ball, O. E. (1984). *Torrance Tests of Creative Thinking Stream-lined* (revised) *annual including norms and directions for administering and scoring figural A and B.* Bensenville Illinois: Scholastic Testing Service, Inc.

Wey, Ming-Tong. (1992). *The tracing study of high school gifted students' earning characteristics and guidance,* third report (Project of National Science Council, NSC 81-0111-003-18), Taipei: National Science Council. (In Chinese)

Wey, Ming -Tong. (1991). *The tracing study of high school gifted students' learning characteristics and guidance,* second report (Project of National Science Council, NSC 80-011-003-25), Taipei: National Science Council. (In Chinese)

Wey, Ming -Tong. (1991). *The tracing study of high school gifted students' learning characteristics and guidance,* first report (Project of National Science Council, NSC 80-011-003-03), Taipei: National Science Council. (In Chinese)

高級中學數理資優學生科學學力與創造力之相關研究

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摘　要

對全國設置數理資優班的十二所高級中學高三資優班學生與普通班學生進行拓弄恩創造力與數理化三科的學力測驗並分析研究。

結果顯示，無論是流暢性、變通性及創造等能力，資優班學生平均得分均較普通班學生高。學力測驗方面，數理化三科資優班學生的得分亦高於普通班學生，可見我國高中數理資優教育受肯定。

在男女生差異方面資優班男生在流暢性、創造性能力及數學、物理的學力較資優班女生優而有顯著的差異；可是普通班男生與女生在創造力和三科學力，均無顯著的性別差異。

數理資優班學生的數理化學力與其創造力卻具有顯著的相關性。

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A Study of Discovery Learning with Different Learning Styles in a CAI Environment

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ABSTRACT

This study was to investigate how students learn in a computer-assisted discovery learning environment. It aimed to carry out discovery learning methods in the curriculum design of CAI for the improvement of the quality of CAI software. The findings of this study include: (1) students with a lower learning outcome spent more time, used more hints and answered the questions more times; (2) whether gender would affect the scores depended on whether the subject was FI (field independent) or FD (field dependent); (3) FI students answered the questions far fewer times, used much fewer hints, and spent even less time than FD students; (4) the learning outcome of FI students was significantly better than FD students; (5) among the three types of discovery learning, A-type learning was the best, followed by B-type and C-type.

Key words: CAI (Computer-Assisted Instruction), discovery learning, learning style

I. Introduction

Bruner (1966) believed that all materials could be represented in some form for learners through "discovery learning." However, it is necessary for teachers to provide students with some guidance in time based on students' individual differences in order to decrease learning time. With the assistance of CAI, the problem of time-consumption in discovery learning may be partially solved. Gagne (1985) proposed that learning of subjects should involve different learning theories. Therefore, this study aimed to examine if discovery learning would make any significant differences for learners with different learning styles in terms of their learning outcomes.

At a time when cognition science and knowledge structuralism prevail, many studies have tried to be interdisciplinary and have integrated different subjects, such as psychology, philosophy, neurology, linguistics, and information science to interpret learners' mental activities and the process of knowledge acquisition. The mental process is related to the structure of knowledge itself and the way conception is constructed. Therefore, a detailed analysis of knowledge will contribute to the development of cognition science and the understanding of the attributes of the teaching material.

On the basis of the above viewpoint, this research is intended to compare whether learners with different orientation (either to liberal arts or to science) and learning styles will react differently to the change in the attributes of the teaching material. A computer-assisted instruction (CAI) courseware, using a complete but not complicated knowledge structure as the teaching material, is developed to discuss the relationship between orientation and learning style and how the discovery teaching method will affect the learning effectiveness of junior high school students.

According to Bloom (1976), a school learning model contained three elements: (1) student characteristics, (2) instruction, and (3) learning outcomes. The learning outcomes could be presented in three aspects: level and type of achievement, rate of learning, and effective outcomes. Most experienced educators believe that superior learning outcomes resulted from the improvement of the quality of instruction. To improve the quality of instruction, instructional designers should take into account students' characteristics, i.e. learning styles, in order to increase their learning motivation and outcomes. Therefore, this study attempted to find out the relationships between learning styles and computer assisted discovery learning.

This research aimed to answer two questions: What learning style of students will benefit most from the discovery learning method? And, what type of discovery learning method will lead to better learning effectiveness? The CAI software teaches the route and the function of blood circulation under three different discovery learning circumstances: not giving any highlight feedback, giving highlight feedback after three errors, and giving highlight feedback whenever an error is made. The measurements of the student performance include learning time per unit and whether the amount of hints and the time taken pointing out errors will affect students' learning.

II. Methods

1. Subjects

The subjects were randomly selected and consisted of 171 junior high school and 38 senior high school students. Subjects were divided into several groups of different learning styles based on the Group Embedded Figures Test (GEFT) scores on the computer. There were 48 field dependent students and 49 field independent students. In the test on blood circulation, 21 of the 209 subjects did not finish within the required time, including 14 of the 77 subjects in A-type, 5 of the 70 subjects in B-type, and 2 of the 62 subjects in C-type. There were 18 questions in the test.

2. Materials

To explore whether students with different learning styles react differently to the same material, this research adopted the Group Embedded Figures Test (GEFT) developed by Witkin, Oltman, Raskin, and Karp (1971) and translated by Ching-Chi Wu.

The CAI software on "blood circulation" was designed, tested, and evaluated by experts. The learning process of the discovery learning in this research was divided into five steps: (1) The input of basic personal data; (2) Embedded Figures Test; (3) pretest; (4) discovery learning (using the computer); (5) posttest. The test questions were presented on the computer.

3. Experimental design and procedures

The variables of the study are as below:

(1) Independent variables: learning styles, individual familiarity with the materials of biology, and discovery learning types

(2) Dependent variables:
  A. the amount of time for each learner to study each learning unit
  B. learning outcomes of discovery learning on "blood circulation"

Tamir (1989) categorized instructional strategy into four levels (from 0 to 3). Instructions at each level could be further divided into three aspects: problem, ways and means, and answers. In this study, subjects were prompted to answer questions. Those under Level-0 circumstances were provided with hints and so underwent learning without discovery. On the other hand, those who were in Level-2 circumstances were not provided with any hints, i.e. they learned by discovery. In addition, those who were in Level-1 circumstances were provided with limited hints so that students could learn by discovery.

The test contained two parts: GEFT and discovery learning. Subjects whose GEFT scores fell in the fourth quartile were defined as "field independent," while those whose GEFT scores fell in the first quartile were defined as "field dependent.". In the second part of the test, the test on blood circulation, three versions of tests were designed with the variations on whether and when to give students feedback in order to investigate if students with different learning styles would show different performance in discovery learning. The three versions are called A-type, B-type, and C-type discovery learning, depending on whether the computer would keep highlighting students' correct answers and offered hints. In the A-type discovery learning situation, students were not provided with any further questions once they responded to the question, while in the B-type learning situation, the students were given the choice whether to have the correct answers highlighted or not once they made an incorrect response. In the C-type learning situation, the computer would offer feedback and choices for prompts after students made three errors. In A and C types of learning conditions, students would be asked whether they needed hints after

Table 1. Types of Feedback and Choosing Prompts

Types	Feedback*	Choosing prompts
A	No feedback at all	Offered after making three errors
B	Offered after making an error	Offered after making an error
C	Offered after making three errors	Offered after making three errors

*Feedback means having the correct answers highlighted.

making three errors while students in B-type condition could ask for hints once they made the first error. A summary of the three types of discovery learning is shown as the table below:

The total time limit for the test consisted of 90 minutes, including about 10 minutes for the computer operation and 20 minutes for the GEFT. The time frame for the discovery learning, the test on blood circulation, was 60 minutes, and the students had to shut down the computer if they could not finish the test within the time frame.

III. Results and Discussion

After the test, the collected data was analyzed in statistical methods such as one-way and two-way ANOVA, the Scheffe and the Tukey test; the report, based on the results and discussion, is as follows.

1. Significant influence of different approaches of discovery learning, learning patterns, and the aptitude of the students (pretest) on the scores (post-test)

The t value, the difference between the pretest and the post-test, was 7.80 with $p<.001$. That is, the students gained significantly higher scores on the post-test (the student's knowledge after receiving discovery learning) than those on the pretest (students' initial knowledge of biology) after the administration of discovery learning. Additionally, the scores on the pretest and the post-test were positively correlated; that is, those who got higher scores on the pretest also did better on the post-test.

(1) In terms of the approach of discovery learning, A-type resulted in the best performance, followed by B-type and C-type.

The difference between the pretest and the post-test in all the three types of discovery learning was quite obvious. Students of all the three types of learning scored significantly higher in the post-test (the student's knowledge after receiving discovery learning) than in the pretest (their initial knowledge of biology).

Table 2. The Effectiveness of Different Discovery Types

Types	Mean	SD	t-value
A(pretest--post-test)	7.57	8.99	6.68***
B(Pretest--post-test)	4.32	9.63	3.62***
C(Pretest--post-test)	3.53	8.07	3.39**

***p<0.01. **p<.01

According to the Tukey test, the different types of discovery learning produced different effectiveness. Subjects under A-type conditions performed significantly better than their counterparts under B-type and C-type conditions ($F=5.23$, $p<.01$.)

Table 3. The Comparison of Different Learning Styles

Types	Mean	A-type	B-type	C-type
A	28.07		*	*
B	22.74	*		
C	25.14	*		

*p<.05

(2) In terms of learning styles, FI students learned better than FD students.

The performances of students in different learning styles were quite different in the post-test ($F=15.66$, $p<.001$). Students of the FI learning styles got higher grades than those of the FD learning type regardless of the types of discovery learning they were assigned to.

Table 4. The Effectiveness of Discovery Learning in Different Learning Styles

Styles	Number of subjects	Mean	FD	FI
FD	49	21.21		*
FI	48	29.20	*	

*p<.05

(3) In terms of grade, senior high school students learned better than junior high school students.

Grade played an important role in performance on the post-test (F=35.41, p<,001). That is, learners of different grades showed different learning effectiveness. The scores of the senior high school students were significantly higher than those of the junior high school students.

Table 5. The Effectiveness of Discovery Learning in Students of Different Ages

Types	Number of subjects	Mean	Junior high	Senior high
Junior	150	23.55		*
Senior	38	33.53	*	

*p<.05

(4) In terms of sex, there was no difference between the learning effectiveness of the two sexes.

There was no obvious difference between the scores of students of different sexes. That is, females did not get higher scores than males, and vice versa.

2. The difference of students in different types of discovery learning on the frequency of using hints, the number of times of answering the questions, and the time spent in answering the questions in terms of learning styles, grade, and sex 1

(1) Learning styles

In all three discovery types, FD subjects used more hints than FI subjects. Among FD subjects, those in B-type discovery learning used hints most often, though in B-type discovery the computer provided subjects with immediate feedback at the first error. In contrast, among FI subjects, those in B-type discovery learning used hints less often than those in A-type or C-type. Moreover, in terms of the frequency of attempts to answering, FI subjects tried fewer times than FD students in all three types of discovery learning. Both FI and FD subjects tried to answer most frequently in B-type discovery learning, followed by A-type and C-type. Finally, in terms of the time spent in answering the questions, in all three types of discovery learning, FD subjects spent more time than FI subjects. Among FD subjects, those in B-type discovery learning needed the longest time, followed by those in A-type. Those in C-type needed the shortest time. Among FI subjects, those in C-type used the shortest time, followed by those in B-type. Those in A-type used the longest time.

Table 6. Students of Different Learning Styles in Different Learning Environments

	Time of using hints	Time of answering	Answering time
A-type	FD>FI	FD>FI	Fd>FI
B-type	FD>FI	FD>FI	Fd>FI
C-type	FD>FI	FD>FI	Fd>FI

(2) Grade

In terms of grade, generally speaking, junior high school students spent more time than senior high school students. In terms of the frequency of using hints, junior high school students in all three types of discovery learning used hints more often than senior high school students. In the case of both senior and junior high school students, those in B-type discovery learning used hints most often, and those in C-type least often. In terms of the number of attempts to answer the questions, senior high school students made fewer attempts than junior high school students in all three types of discovery learning. Among the junior high school students, those in C-type discovery learning tried the fewest times, and those in B-type tried the most. Among the senior high school students, those in C-type discovery learning tried the most, and those in B-type, the least. Finally, in terms of the time spent in answering the questions, in all three types of discovery learning, junior high school students spent more time than senior high school students. Among junior high school students, those in A-type discovery learning spent the longest time, and those in C-type spent the shortest time. Among senior high school students, those in C-type spent the longest time, and those in B-type spent the shortest time.

Table 7. Students of Different Age Groups in Different Learning Environments

	Time of using hints	Time of answering	Answering time
A-type	J>S*	J>S	J>S
B-type	J>S	J>S	J>S
C-type	J>S	J>S	J>S

*J: Junior, S: Senior

(3) Sex

In terms of sex, generally speaking, males used more hints than females regardless of which conditions they were under. In terms of the number of attempts to answer the questions, males tried more times than females. In terms of the time spent in answering the questions, females spent more time than males. Among the males, those in B-type discovery learning used most hints, followed by those in C-type and A-type respectively. Among the females, it was also those in B-type who used hints most often, followed by those in A-type and C-type. In terms of the frequency of answering the questions among these three types of discovery learning, females answered more times than males in A-type discovery learning while in B-type and C-type, males answered more times than females. Furthermore, among the male subjects, those in B-type discovery learning answered most times, and those in A-type answered the fewest times. Among the female subjects, those in A-type made the most tries, while those in B-type made the fewest tries. Finally, in terms of the time spent in answering the questions, females in all three types of learning spent more time than males. Among the males, those in A-type spent the longest time, and those in C-type spent the shortest time. Among the females, those in A-type spent the longest time, and those in B-type spent the shortest time.

Table 8. Students of Different Gender in Different Learning Environments

	Time of using hints	Time of answering	Answering time
A-type	M>F*	M>F	M>F
B-type	M>F	M>F	M>F
C-type	M>F	M>F	M>F

*M: Male, F: Female

3. The correlation between the scores on the post-test and other variables such as the time spent in answering the questions, the frequency of using hints, and the number of attempts at answering the questions in terms of types of discovery learning, sex, grade, and learning styles

(1) Types of discovery learning

In all three types of learning, (A) those who got lower scores in the post-test spent more time (in A-type, r=-.72; in B-type, r=-.68; in C-type, r=-.59); (B) those who got lower scores used hints more often (in A-type, r=-.60; in B-type, r=-.48; in C-type, r=-.40); (C) those who got lower scores tried the most times (in A-type, r=-.73; in B-type, r=-.77; in C-type, r=-.67).

(2) Sex

Among both male and female subjects, (A) those who got lower scores spent more time (M: r=-.53, F: r=-.66); (B) those who got lower scores used hints more often (M: r=-.50, F: r=-.48); (C) those who got lower scores answered more times (M: r=-.74, F: r=-.71).

(3) Grade

Among both junior and senior high school students, (A) those who got lower scores spent more time (Junior: r=-.52, Senior: r=-.65); (B) those who got lower scores used hints more often (Junior: r=-.43, Senior: r=-.35); (C) those who got lower scores tried more times (Junior: r=-.70, Senior: r=-.29).

(4) Learning styles

Among FD and FI subjects, (A) those who got lower scores spent more time (FD: r=-.64, FI: r-.50); (B) those who got lower scores used hints more often (FD: r=-.51, FI: r=-.34); (C) those who got lower scores answered more times (FD: r=-.73, FI: r=-.69).

4. The effect of the interaction among sex, grade, and discovery learning types on the scores of the post-test, the times of using hints, the frequency of answering the questions, and the time spent in answering.

(1) Sex

A. Only discovery types affected the number of times of using hints, but not the interaction between sex and different discovery types (F=2.03, p>.05).

B. The examination of the interaction between sex and different discovery types and the scores of the post-test showed that only different discovery types affected the scores, but not the interaction between sex and the discovery type. That is, the interaction between sex

Table 9. Male and Female Means and SD's of the Number of Times of Using Hints in Different Discovery Type

		A-type	B-type	C-type
Male	Mean	4.55	7.81	2.33
	SD	7.27	10.57	11.35
Female	Mean	3.25	5.02	2.51
	SD	4.06	7.92	3.94
Total	Mean	3.74	6.06	3.74
	SD	5.48	9.02	8.10

and the discovery type did not affect the effectiveness of learning (F=2.05, p>.05).

C. The interaction between sex and different discovery types did not affect the frequency of answering the questions.

Table 10. Male and Female Means and SD's of the Frequency of Answering in Different Discovery Types

		A-type	B-type	C-type
Male	Mean	52.97	65.81	59.93
	SD	34.16	46.08	33.96
Female	Mean	58.08	51.11	54.60
	SD	39.81	30.52	26.96
Total	Mean	56.16	56.57	56.92
	SD	37.64	37.43	30.07

D. The interaction between sex and different discovery types did not affect the time spent in answering the questions.

(2) Grade

Table 11. Male and Female Means and SD's of Time Spent in Answering the Questions

		A-type	B-type	C-type
Male	Mean	25.81	21.67	19.90
	SD	17.11	9.72	10.78
Female	Mean	26.24	23.56	24.14
	SD	15.86	12.91	11.31
Total	Mean	26.09	22.89	22.29
	SD	16.19	11.84	11.19

A. The interaction between different grades and different discovery types did not affect the scores (F=2.14, p>.05); however, grade and different discovery types did affect the scores of the post-test. That is, the interaction between different grades and different discovery types did not affect the effectiveness of learning.

Table 12. Junior High School Students' and Senior High School Students' Means and SD's of the Scores of the Post-test in Different Discovery Types

		A-type	B-type	C-type
Junior	Mean	27.57	21.06	22.12
	SD	9.37	11.00	9.31
Senior	Mean	33.21	34.56	32.00
	SD	4.92	3.58	3.93
Total	Mean	28.83	24.38	23.43
	SD	8.87	11.32	9.39

B. The interaction between different grades and different discovery types did not affect the effectiveness of learning (F=0.14, p>.05) ; however, only different discovery types affected the times of using hints.

Table 13. Junior High School Students' and Senior High School Students' Means and SD's of the No. of Times of Using Hints in Different Discovery Types

		A-type	B-type.	C-type
Junior	Mean	4.41	7.26	4.28
	SD	5.81	9.85	8.55
Senior	Mean	0.71	2.00	0.13
	SD	1.64	2.90	0.35
Total	Mean	3.74	6.06	3.74
	SD	5.48	9.02	8.10

C. The interaction between different grades and different discovery types did not affect the frequency of answering the questions (F=0.14, p>.05); however, only different discovery types affected the frequency of answering the questions. That is, the interaction between different grades and different discovery types did not affect the effectiveness of the learning.

D. Only different discovery types affected the time of answering the questions; however, the interaction between different grades and different discovery types did not affect the time of answering the questions (F=0.53, p>.05).

Table 14. Junior High School Students' and Senior High School Students' Means and SD's of the Frequency of Answering the Questions in Different Discovery Types

		A-type	B-type	C-type
Junior	Mean	61.14	63.50	59.46
	SD	39.90	39.94	30.89
Senior	Mean	33.71	33.19	39.75
	SD	4.97	7.19	16.35
Total	Mean	56.16	56.57	56.92
	SD	37.64	37.43	30.07

Table 15. Junior High School Students' and Senior High School Students' Means and SD's of the Time of Answering the Questions in Different Discovery Types

		A-type	B-type	C-type
Junior	Mean	29.61	26.13	23.63
	SD	16.48	11.88	11.34
Senior	Mean	13.27	12.98	13.28
	SD	4.35	2.62	22.29
Total	Mean	26.09	22.89	22.29
	SD	16.19	11.84	11.19

5. *The effect of sex, grade, discovery types, and learning styles on the scores, the times of using hints, the frequency of answering the questions, the time spent in answering the questions*

(1) Scores

A. The interaction of sex and different learning styles had an obvious effect on the scores (of the post-test) ($F=5.39$, $p<.05$). That is, whether sex would affect the scores depended on what learning style (FI or FD) the subject belonged to. After further analysis, it was found that FI male subjects got the highest scores, followed by FI female subjects. FD male subjects got the lowest scores of all.

B. The interaction of different grades and different discovery types did not have an obvious effect on the scores ($F=3.42$, $p>.05$); however, grade and discovery types did affect the scores (of the post-test). That is, the interaction between different grades and different discovery types did not affect the scores.

C. The interaction of different learning styles and different discovery types did not have an obvious effect on the scores ($F=1.36$, $p>.05$); however, learning styles and discovery types did affect the scores (of the post-test). That is, the interaction between different learning styles and different discovery types did not affect the scores.

(2) The times of using hints

A. The interaction of sex and different learning styles had an obvious effect on the times of using hints ($F=10.39$, $p<.01$). That is, whether sex would affect the times of using hints depended on what learning style (FI or FD) the subject belonged to. After further analysis, it was discovered that FD male subjects used the most hints, followed by FI female subjects. FD male subjects used the fewest hints of all.

B. The interaction of different grades and different learning styles did not have an obvious effect on the times of using hints ($F=2.07$, $p>.05$). That is, the interaction of different grades and learning styles did not affect the number of times of using hints.

C. The interaction between different discovery types and learning styles did not have an obvious effect on the times of using hints ($F=2.54$, $p>.05$); however, different learning styles did affect the no. of times of using hints. That is, the interaction between different learning styles and discovery types did not affect the no. of times of using hints.

(3) The frequency of answering the questions

A. The interaction of sex and different learning styles had an obvious effect on the frequency of answering the questions ($F=6.88$, $p<.05$). That is, whether sex would affect the frequency of answering the questions depended on what learning style (FI or FD) the subject belonged to. After further analysis, it was discoveved that FD male subjects answered the questions most times, followed by FD female subjects. FI male subjects answered the fewest times of all.

B. The interaction of different grades and different learning styles did not have an obvious effect on the number of times of using hints ($F=3.51$, $p>.05$), but grade and learning styles did affect the frequency of answering the questions. That is, the interaction of different grades and learning styles did not affect the frequency of answering the questions.

C. The interaction between different discovery types and learning styles did not have an obvious effect on the frequency of answering the questions (F=2.24, p>.05); however, different learning styles did affect the frequency of answering the questions. That is, the interaction between different learning styles and discovery types did not affect the frequency of answering the questions.

(4) The time spent in answering the questions

A. The interaction between sex and different learning styles did not have an obvious effect on the time spent in answering the questions (F=2.24, p>.05); however, different learning styles did affect the time spent in answering the questions. That is, the interaction between sex and different learning styles did not affect the effectiveness of learning.

Table 16. Male and Female Mean and SD's of the Time Spent in Different Learning Styles

		FD	FI
Male	Mean	30.53	15.85
	SD	15.19	9.76
Female	Mean	27.22	20.87
	SD	14.96	11.97
Total	Mean	28.46	19.03
	SD	14.98	11.37

B. The interaction between different grades and different learning styles did not have an obvious effect on the time spent in answering questions (F=3.89, p>.05); however, both grade and learning styles affected the time spent in answering . That is, the interaction between different grades and learning styles did not affect the time spent in answering the questions.

C. The interaction between different discovery types and different learning styles did not affect the time spent in answering; only different learning styles affected the time spent in answering the questions.

Table 17. Junior High School Students' And Senior High School Students' Means and SD's of the Time Spent in Answering

		FD	FI
Junior	Mean	30.53	15.85
	SD	15.19	9.76
Senior	Mean	27.22	20.87
	SD	14.96	11.97
Total	Mean	28.46	19.03
	SD	14.98	11.37

Table 18. The FI Students' and FD Students' Means and SD's of the Time Spent in Answering the Questions

		A-type	B-type	C-type
FD	Mean	31.03	33.42	23.90
	SD	19.12	14.87	11.47
FI	Mean	22.72	17.52	16.56
	SD	14.35	9.86	8.44
Total	Mean	26.16	24.70	20.92
	SD	16.69	14.57	10.86

IV. Conclusion and Suggestions

1. Conclusion

CAI is not a new idea, but it is very difficult to apply it to teaching because the computers in most junior high schools in Taiwan are seriously inadequate and outdated. However, most students are not unfamiliar with the computer because it is quite common to have a PC at home. The discovery learning approach is different from the traditional one-way instructive teaching in that it develops in students the ability to think independently and solve their problems by means of using CAI.

In this study, three versions of CAI programs on blood circulation were designed for three different types of discovery learning. All versions were based on the standard biology textbook used in all Taiwan junior high schools. It intended to find out which type of discovery learning is most suited for students with a certain learning style by varying the time of giving feedback and by providing different choosing prompts.

The main results of this study were as follows:

(1) An obvious positive correlation existed between the pretest and the post-test. Namely, the better the students' initial knowledge on blood circulation was, the more effective their learning methods were.
(2) Grade, learning style, and type of discovery learning affected learning (the scores on the post-test), but sex did not.
(3) Among the three types of discovery learning, A-type learning was the best, followed by B-type and C-type. FI students performed far better than their FD counterparts.
(4) The students who got lower scores spent longer time, used more hints and answered the questions more times (i.e. they made more mistakes).
(5) FI students answered the questions far fewer times, used far fewer hints, and spent even less time than FD students. And obviously the learning effectiveness of FI students was better than FD students.
(6) The interactions between grade or sex and different types of discovery did not affect the scores of the post-test, the times of using hints, the frequency of answering the questions, and the time spent in answering the questions.
(7) The interaction between sex and different learning styles had an obvious effect on the scores of the post-test; whether sex would affect the scores depended on whether the subject was FD or FI. However, the interaction between different grades and discovery types did not affect the scores on the post-test.
(8) The interaction of sex and different learning styles had an obvious effect on the scores of the post-test; whether sex would affect the scores depended on whether the subject was FI or FD. However, the interaction of different grades and discovery types did not affect the scores on the post-test.
(9) The interaction between sex and different learning styles had an obvious effect on the frequency of answering the questions; whether sex would affect it depended on whether the subject was FI or FD. However, the interaction between different grades and learning styles did not affect it.
(10) The interaction between sex or grade and different learning styles affected the time spent in answering the questions.

The results of the study showed that the main factor affecting learning effectiveness was the students' initial knowledge of biology. Moreover, students' learning styles and the type of discovery learning affected learning effectiveness, too. Among the three types of discovery learning, the effectiveness of A-type was the best. This is perhaps because the students in B-type and C-type learned through trial and error, which imposed a negative influence on their learning. In addition, the FI students learned better than the FD students because the FI students depended less on the hints and the effect of highlighting.

2. Suggestions

Several suggestions on discovery learning by means of CAI can be made based on the results of the study :

(1) The design of discovery learning should vary depending on the learning style of the student. More discovery instruction can be given to students who are less subject to the influences of their outer environment. Similarly, for those who are more field dependent, discovery instruction should be carried out along with traditional teaching in a suitable proportion.
(2) The content of the discovery learning should take students' knowledge backgrounds into consideration. More hints should be provided to poorer learners. On the other hand, students with better learning abilities or at higher grades can be given more difficult material (with fewer hints).
(3) The results showed that the interaction between sex and different learning styles affected the scores of the post-test, the number of times of using hints, and the frequency of answering the questions. FI male students got the best learning effects, and FD male students, the poorest. Therefore, discovery learning is quite suitable for male and FI students, but not for FD ones, either male or female. The design of CAI instruction should vary depending on sex and the learning styles of the students.
(4) Among all three types of discovery learning, the learning effectiveness of the students in A-type was the best, and the interaction between sex or grade and different discovery types did not affect the effectiveness of learning, the number of times of using hints, the frequency of answering the questions, and the time spent in answering the questions. As a result, A-type discovery learning was advantageous to learners of each sex and at different grades. In other words, whenever a learner makes a mistake, he should be encouraged to try again before the correct answer is provided. In doing so, learners' understanding of the ques-

tion and their learning outcomes can be enhanced.

References

Bloom, B. S. (1976). *Human characteristics and school learning*. New York: McGraw-Hill.

Bruner, J. S. (1966). *Toward a theory of instruction*. New York: W. W. Norton.

Gagne, R. M. & Briggs, L. J. (1979). *Principles of instructional development*. Chicago: Holt Rinekard and Winoton.

Hong, J. C. (1987). CAI system consideration: A model of courseware design strategy. *Computer Education*, June, 10.

Keefe, J. W. (1987). *Learning style theory & practice*. Reston, Virginia: National Association of Secondary School Principals.

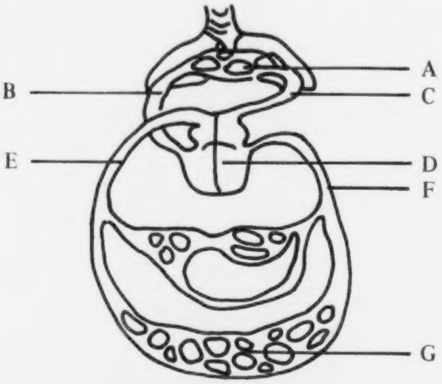
Tamir, P. (1989). Cognitive preferences of Jewish and Arabian high school students who studied an inquiry-oriented biology curriculum for several years. *Research in Science and Technology Education*, *1*(1), 17-26.

Witkin, H. A., Oltman, P. K., Raskin, E. & Karp, S. A. (1971). *A manual for the embedded figures tests*. New York: Consulting Psychologists.

Appendix

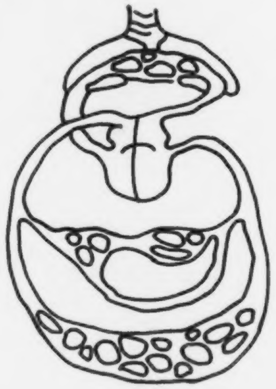
Sample questions:

I. 填圖題（請填入英文代號）



1. 主動脈是左圖的那一個部位？B
2. 肺靜脈是左圖的那一個部位？F
3. 在體（大）循環過程當中，交換養分、廢物的場所是：___
4. 肺（小）循環的過程是：___ → A → ___

II. 請列出血液由左心室出發，經由體（大）循環、肺（小）循環，再回到左心室的所有過程。



A. 心　臟	B. 肺泡壁微血管
C. 左心房	D. [illegible]
E. 右心室	F. 肺動脈
G. 主動脈	H. 小動脈
I. 肺靜脈	J. 大靜脈
K. 小靜脈	L. 微血管

你的答案是：

〔左心室〕→ G → H → D → 　→ J →

→ E → 　→ 　→ I → C →〔左心室〕

按<F1>鍵可修改答案　　請以上下左右鍵選答後，按空白鍵確認。

不同學習型態的學生在發現式學習CAI環境中的學習成效

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摘　要

本研究探討學生如何在發現式學習環境中學習，期使發現式學習方式更易落實於CAI課程設計中，以提昇CAI軟體品質。本研究的結果包括：(1)學習成效越低的學生其答題時間、使用提示之數、答題次數上均越多；(2)性別對學習成效、使用提示次數、答數次數之是否有影響均賴學生之學習型態而定；(3)場地獨立的學生其答題時間、使用提示次數、答題次數均明顯少於場地依賴的學生；(4)場地獨立學生之學習成效明顯較場地依賴學生佳；(5)三種發現式學習中，以(1)發現式學習的成效最佳，(3)發現式學習次之，最後爲(2)發現式學習。

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An Ethnographic Analysis of Variables Related to an Elementary School Science Teacher's Performance

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ABSTRACT

The purpose of this study was to understand an experienced elementary school teacher's science teaching. An interpretive research method was adopted. A literature major teacher with four years teaching experience was selected, observed and videotaped. School administrators, teachers and students were interviewed. The findings of this study indicated that there was a consistent relationship between the teacher's beliefs in science and her science teaching. However, when the teacher felt uncomfortable with her science knowledge, she had difficulties in putting her beliefs into practice. Help from the experienced teachers and administrators were important for the teacher's professional development.

Key words: elementary school science teaching, teacher education, case study

I. Introduction

1. Need and Purpose

The reform of science curriculum in the U. S. A. during the 1960's-70's had focused on the improvement of science education. However, students' science achievements did not improve. Students became less interested in science and took less science courses (Helgeson *et al.*, 1977; Weiss, 1978). In the Republic of China, similar phenomena happened. Many students decided to be liberal arts majors in grade ten (Wei & Yang, 1988). They took only required science courses and no more optional science courses after grade 10.

Research related to teacher behavior (Balzer *et al*, 1973) helps us better understand "effective" teaching. However, we still need further information on which factors block students from learning science.

Research on learning has moved from focusing on Piaget's development stage, through Neo-Piagetians' mental stage and personal constructivism's concepts change, to recent thinking on learning from the perspectives of social interaction and culture (Cobern, 1993). This is one approach to understand learning. On the other hand, understanding teachers and interactions within the classroom is another approach to the study of learning.

If we accept that teaching is a continuous decision making process (Mosston & Ashworth, 1990), then we need to know what decisions teachers make when they teach, how teachers make decisions when they teach, and why they make such decisions.

There is a ongoing need to identify and understand what teachers do, and what teachers have students do, to create learning environments. There is also a ongoing need to identify and determine how these successful teaching and learning practices can be developed by teachers, and how school systems can help nurture the conditions that encourage the development and use of these practices.

The author has observed several elementary school science courses taught by novice teachers over the past three years. It was the author's intent to observe some experienced science teachers' teaching in order to make comparisons with beginning teachers.

It was expected after several case studies that we can better understand variables which can nurture conditions to help elementary school teachers perform better in their science teaching.

Learning from observations of elementary school science teaching, the author believes that "good" science teaching is influenced heavily both by a teacher's personal traits and the school environment.

The purposes of this study were to observe an elementary school science teacher who is considered "good" by the school administration and to develop an understanding of the traits, preparation, and conditions that helped her perform better.

II. Research Questions

This study tried to understand the following research questions:

(1) What are the variables that relate to a teacher performing better at science teaching?
(2) How does a teacher's science knowledge influence his/her science teaching?
(3) What are the factors that help a teacher develop?

III. Method

1. Selection of a School

The school selected was a school located near the author's office at the second campus of the National Taiwan Normal University, and was reputed to be a "good" school.

The school has 207 classes with more than 10,000 students; each class has about 50 students. There were 302 teachers in the school.

The first principal had been in charge of the school for a long time. All the rules and guidelines in the school had been designed and set up by him in a way to improve teaching and learning. After the first principal retired, most of the rules and guidelines have remained unchanged.

In each grade, a teacher was elected to serve as chairperson to help organize and communicate among administrators and teachers. The communication among teachers and administrators is very good within the school.

A shortage of special staff to maintain laboratories is a common problem in all elementary schools. However, the maintenance of the equipment and supplies was very efficient, adequate and convenient in this school. In the Republic of China, all elementary students have to share the responsibility of keeping their school campus neat and clean. This school assigned one class to take care of lab equipment instead of asking this class to clean school yards. As a result, students help clean and maintain laboratory equipment. There are two periods every day for teachers to borrow and return equipment. Ms. Wong said "I feel that this system is convenient and helpful to my preparations for teaching". There are no maintenance problems at this school.

After interviewing with the chairperson of science studies, the author learned that her concept of elementary education is "good behavior and habits are more important than acquisition of knowledge". Therefore, the school emphasizes the training of students' behaviors and neatness. The class which wins the championship of good behavior or neatness will be announced openly. There is no comparisonship of academic achievement among classes. This is quite different from some other schools.

The campus is not big enough compared to the number of students the school has. Everything within school is cared for an orderly way. Students share the responsibility of keeping the campus neat and in order.

The school respects parents' opinions or suggestions—such as concerning the amount of homework or the way to help children correct their misbehavior—very much. Sometimes, the school may ask teachers to adjust their standards to meet parents' expectations, such as either increasing or decreasing students homeworks, or instituting more or less requirements affecting students' behavior.

There is a chairperson for each subject. The chairperson is a consultant for teaching that specific subject and has to assist colleagues. The chairperson's teaching load is reduced by 4-8 hours per week.

Teachers in the school get along well and help each other when there are any questions related to teaching.

Each grade has the same monthly tests and quizzes in all subjects—including science. There are three monthly tests and three quizzes each semester. Teachers take turns preparing the tests.

2. Selection of a Teacher

The teacher, Ms. Wong, was selected based on the recommendation of the chairperson of studies and the chairperson of science teaching. They both rated her as a "good" teacher. Ms. Wong was the first experienced science teacher the author observed.

Ms. Wong was a literature major when she studied in a junior teacher college. She completed one year of course work in biology, chemistry, and physics and one-half year of course work in earth science. She has been teaching for four years and has taught science three years. She has good verbal skills and a quick mind. She meets people easily and exhibits poise in many situations. She is considered friendly and kind by her students.

3. The Classes

Based on the author's time and Ms. Wong's class schedule, two of Ms. Wong's classes were observed. One was a grade 6 science class and the other was a grade 5 science class.

Students had science class in their regular classroom. However, tables and chairs were rearranged for science classes so that students had a good workspace for doing activities in small groups.

There were 48 students in the grade 6 class—24 boys and 24 girls. Students were mostly from average to above average social economic levels and academic aptitude levels. There were 48 students in the grade 5 class—25 boys and 23 girls. These students were from similar home environments as the grade 6 class and were also mostly average to above average academic ability.

Both classes primarily used text materials with supplemental materials as provided by the Ministry of Education.

4. Data Collection

Data was obtained by (1) observing and videotaping the teacher during the teaching of four science units (in May-June 1991 for grade 6 and in April-May 1992 for grade 5), (2) interviewing the teacher and students, (3) obtaining data related to the school and the teacher by interviewing administrators, (4) examining classroom materials used by the teacher, and (5) making general observations of the school, students, and teachers.

In the Republic of China from grade 3 to grade 6, there are four science class sessions per week. Each session is 40 minutes long. Schools will usually arrange two days per week and each day has two science sessions.

The four science units observed were "Environmental Pollution" and "Earth and Our Life" for grade 6 and "Electricity and Magnetism" and "Lens" for grade 5. Each unit is approximately 2-3 weeks in length.

Field notes were taken when teaching was observed. Video tapes were analyzed for student–teacher interactions using a modified Flanders Interaction Analysis Procedures (Flanders, 1962); level of questions asked by the teacher were analyzed using Blosser's Question Category System (Blosser, 1973), instructional strategies and science content analysis. Video tapes were also analyzed by the author and two former students who are elementary school teachers. One has an M. A. degree. One is studying for an M. A.. Notes were taken individually by each.

For the purpose of answering questions raised by classroom observations and also in data triangulations, structured questions were used in interviews with teacher and administrators. Students were interviewed informally. Responses of teacher and administrators were recorded and analyzed.

Materials used in the classroom were analyzed and notes on the analyses were recorded in the field notes. Questions related to these materials were clarified or modified in discussions with the teacher.

5. Data Analyses

The data obtained were analyzed by (1) categorizing findings, (2)identifying relationships among the findings within each category and between categories, (3) identifying patterns that evolved, and (4) determining if constructs related to the patterns that evolved from the analysis.

IV. Analyses Related to the Research Questions

The data were analyzed to determine relationships, patterns (congruence and lack of congruence), and constructs related to patterns. The assertions with supporting data were developed from these analyses.

ASSERTION 1. A substantial amount of this tea-cher's classroom performance was related to her personal traits and characteristics.

The analyses provided a composite picture of a teacher with many personal traits and characteristics that helped her to be successful in the classroom. She was friendly and enjoyed working with children, had a positive self–image, exhibited poise and self-confidence when teaching, had good verbal ability, was not afraid to admit when she did not know information, and was interested in self-improvement.

Ms. Wong believes that students are the center of learning. She said:

> The relationship between teacher and students should be a friendly one. (In traditional

> Chinese culture, teacher and student are like parent and child. A teacher has more authority). Teacher should help, stimulate, and motivate student learning. However, students have to discover and summarize the learning content. A teacher certainly has some influence on students learning. But, learning mainly depends on students themselves. As a teacher, I will be very careful to understand what students already know, and then decide what I am going to teach.

Based on this concept of learning, it seldom happened that Ms. Wong lectured in the front while students listened at their seats in her class. She always tried to motivate students' interest in learning by telling jokes or encouraging students to work for extra points. There were many student activities in her class. Most teachers worry that if they let students do activities, students will become too noisy and teachers would not get the students' attention back again. This is not a problem for Ms. Wong. In her class, no matter what students were doing, as soon as Ms. Wong said the key word, students would be quiet and listen to her. These key words were some words such as "One, Two, Three, Wooden man", or "Back to the Team".

I asked her how she decided to use these key words. She said:

> There is no specific word, we choose a word both me and students agree on. Then we use it as a signal for me to call for their attention.

"Why not use the word 'Attention' ?", I asked. She said:

> It is too serious. Kids like the word they choose.

The atmosphere in her science class is relaxed and harmonious. Both Ms. Wong and her students enjoy their science class.

Ms. Wong cares very much about what students already know and their feelings. There was an activity in which she asked students to connect a straightline circuit and watch how the magnetic needle rotated when she taught the unit "Electricity and Magnetism". While students did activities, Ms. Wong moved around. She found that some students did not know how to use a magnetic needle to tell the directions. She stopped the activity and reviewed how to recognize the directions and how to use the magnetic needle to tell direction. After she was sure that all students knew the directions and the use of a magnetic needle, she then continued the activity.

Her relaxed classroom style (while maintaining respect, order, and control) helped to make students comfortable. In the beginning of observing the class, I went along for the first week to let students get used to have someone else in the class. Thereafter, my assistant with a camera went with me. The first time my assistant and I brought the video-camera to the class, students seemed a little nervous and curious. Ms. Wong said:

> Today we have three guests–Professor Lee, Ms. Fang and (she pointed to the camera) the one you are familiar with. I hope you will study as usual.

Students followed her finger and turned their heads to look at us, smiled and relaxed.

On the 29th of April, 1992, many visitors sat in Ms. Wong's class to observe her teaching. She walked into the classroom and smiled as usual. After students gave their bows, she asked students take a deep breath and follow her by breathing air out slowly. After several deep breaths, she started to teach. After the class, I asked her why she asked students to take deep breaths. She said:

> When I walked into the class, I found some students were too excited and curious about visitors and some are too nervous. Deep breath could calm students down, release their tension and keep them concentrated. In fact, it also help me release my tension.

She smiled when she answered my question.

Ms. Wong's pronunciation is very clear and her communication skills are good. When she taught the "Environmental Pollution" and "Earth and Our Life", she redesigned the activities from the Teacher Guide and had each group prepare different topics and report to the class in the next sessions. Both Flanders interaction analysis and field notes indicated that she spent 11-13 minutes explaining what students had to do until all her assignments and requirements were clear to students. Students understood clearly and performed well.

Ms. Wong not only redesigned the instruction of the above two units, but also modified the content of the units to be more relevant to daily life. Students were interested and spent lots of time preparing. In class, some students asked some very specific questions. If she did not know the answer, she would say:

> I do not know the answer. Does anyone know the answer?

Ms. Wong told me that in the summer, when she had time, she often went back to the junior teacher college that she had graduated from and studied with one of her previous professors who had taught her "how to teach social science". She said that she had learned much from this professor and still could learn new ideas from him. She said that she had applied some of those ideas to her science classes.

Ms. Wong often reflects on her lesson plans and modifies activities during the day if plans do not work as well as expected with early classes.

ASSERTION 2. Preinstructional practices can help a teacher be more successful in her instruction. Preinstructional behavior is strongly influenced by subject knowledge and pedagogical knowledge.

Ms. Wong spent considerable time planning and considering how to teach the units. During interviews, she said :

> In the first year when I taught science, it took me 3-4 hours to prepare a regular unit. If it was difficult for me, it took me at least 5-6 hours to prepare the lesson. During the second year, some materials still took me at least 2-3 hours to prepare. I would focus on the notes and rethink how to modify the activities which were difficult to teach during the last year.

Among her major considerations were the level of pupils (thinking, age), the interests of the pupils, the content of the unit, the types of activities that were adaptable to the unit, and previous success or lack of success of units and activities in previous years' classes.

Her planning tends to focus on whether to alter materials, use of relevants and concrete experiences and examples, ways to focus the unit and ways to involve the students in thinking.

She redesigned a two-stage debate when she taught "Environmental Pollution". The topic was a hot issue in Taiwan----"Should we build the fourth nuclear power plant?". Students loved the activity, and everyone was involved in collecting information or making posters. Students were excited to have a debate in class.

After the class, I asked, " Why did you select this topic to debate, since it was not covered in the textbook?" She said:

> Since it is related to environmental pollution and also a hot issue in our society currently, although the content is not covered in the textbook, I think to have students think the problem from various perspectives is a good experience, and so I chose this content to be taught.

"How do you think of two-stage debate?" another observer asked.

She said:

> I was a member of 'debate club' in junior teacher college. I had experience in debating. It is an idea modified from my experience. However, formal debate procedure can only involve few representatives. I modified the procedure into a two-stage approach in order to have all students be involved.

The author worked with her in preparing to teach the unit of the "Lens". When we discussed how to introduce the "focal point" to students, she said:

> For 5th graders, the best way for them to understand "focal point" is to have them to burn something through the lens.

In the Spring, sunny day are not frequent in Taiwan. So as soon as there was sunshine in a morning, she temporarily stopped the activities of the "Electricity and Magnetism" unit and brought students outdoors to learn "focal point".

ASSERTION 3. Teacher's beliefs are like a compass directing his/her teaching.

Ms. Wong believes that: "Science can train human beings' thinking ability through the training of scientific process skills. Natural science has more impact on human beings than human science. Natural science can help human beings be more efficient. Art and literature and natural science can be complementary." She also believes that science knowledge will change, but not thinking ability.

What is thinking ability? Ms. Wong's explanation is: "The ability to discover problems, search for answers, make decisions and get the best answer."

What are her goals for science teaching? She said:

> The goals of science teaching in my class are to develop students' creativity and prepare them to have the ability to solve their daily life problems.

The above mentioned examples reveal some of her beliefs in science and science teaching. One other example can explain how she emphasized thinking ability. In order to encourage students to think and talk, after questioning students, sometimes she would say:

> No matter if the answer is right or wrong, if you give an answer, you will get one point.

Sometimes she would say:

> If your answer is correct, you will get 2(or 3,4...etc..) points.

In the unit of "Electricity and Magnetism", there was a question concerning "what are the variables that influence the strength of the electrical magnetism?". Students eagerly answered the question. After most possible answers were mentioned, one student was upset and complained:

> Why don't you let me answer? All the answers have been given by others. I have no more answers.

Ms. Wong smiled and said:

> You think again. If the answer is possible, I will accept it and give you more points. In the beginning, one correct answer gets one point. Now you may get 3 or 4 or more points if your answer is correct.

Students were excited and tried to think of other possible answers. Some were nonsense. But since some answers made sense, the students got more points. During our interview, she told me that she had given a student 16 points for a correct answer before. This was the highest number of points awarded.

ASSERTION 4. A substantial amount of a teacher's classroom performance at the elementary school level is related to (1) their teacher-student relationships and interactions and (2) cultural patterns related to teacher-student interaction.

Ms. Wong generally was very successful in teacher-student relationships and interactions. From the above examples, it was clear she was able to motivate a high percentage of students to complete assignments and be involved in activities. She was also able to facilitate a substantial amount of student-student interaction through the activities she selected and the climate in her classroom. However, a classroom with a teacher having her teaching style and her rapport with students often has a higher frequency and percentage of questions asked by students. However, compared to another class observed by the author which was located in Taipei city, and where students' parents had a high educational background, lower numbers of questions were asked by students in Ms. Wong's class. This may be a cultural pattern.

ASSERTION 5. Several different instructional styles were observed in Ms. Wong's classes. Mainly content influences when and how these styles are implemented. Teacher knowledge also influences the success of the styles implemented.

Ms. Wong stated that she had four general teaching styles. Three of these styles were observed in both the grade 5 and grade 6 classes. Her instructional styles as observed were (1) a style for stimulating students' preparations of lessons, reporting or discussions in class, (2) a style for laboratory and group discussions during an activity, and (3) a style used at the conclusion of units. Observations and analyses of tapes indicated that each style generally yielded a similar questioning pattern , a similar teacher-student interaction pattern, and a similar sequence.

Results from modified Flanders Interaction Analysis and questioning analysis indicated that in the first style, about 20% of class time was spent asking questions and 50% of questions encouraged either convergent, divergent or evaluative thinking; 26-34% consisted of students talking; 7-11% was spent doing laboratory work. In the second style, on the average, teacher asked questions for 9% of class time, students did laboratory work for 16-46% of classtime, and 11-54% of time was taken up by students talking. In the third style, 20% of time was used for teacher explanations, 20% was taken up by questions and answers, and 50% was used for students discussing, writing, or reading.

How did she decide which instructional styles to use when she prepared the lesson? She said:

> When the content is more daily life oriented—such as in the units of "environmental pollution" and "earth and our life"—I will use style one. If the content is more theoretical concept related—such as the units of "lens" and "electricity and magnetism"—I will choose the second style. At the end of each unit, when I tried help students to review the content, I choose the third style.

The success of these styles depends not only on the instructional strategies used, but also the teacher's knowledge of the content and of the student's prior knowledge.

When Ms. Wong taught the "Electricity and Magnetism", the author found that she followed the teacher's guide closely. She did less modification than other units. I asked, "Why?". She said:

> One reason is because that content is more abstract and not life-related. Another reason is that I do not feel comfortable modifying the activity since I am uncomfortable with the content.

She also told me that she was not clear about electricity and magnetism since the physics course at teacher college. Last year, a colleague who graduated from the industrial technical college and served as a temporary teacher in her school helped her understand these concepts much better. Nevertheless, she said that she still felt uncomfortable modifying the learning activity.

ASSERTION 6. Teacher's science knowledge not only influences how the teacher prepares a lesson but also how she asks questions.

Ms. Wong said:

> In general, I think that I was well prepared to teach in elementary school by the education I received in junior teacher college. However, science content had bothered me during the first year I taught science. I overcame it by discussing with colleagues and reading. The subject matter chairperson helped me very much, especially in the first year I taught science. I still feel uncomfortable with earth science.

Besides the above mentioned example of the unit of "electricity and magnetism" in which Ms. Wong followed the teacher's guide closer than other units, observations also indicated that Ms. Wong's lack of content knowledge affected the extent to which she questioned students when they made unclear or incorrect statements.

In the unit of "earth and our life", students reported some content that was not covered in the textbook. This content included: "Oil was formed through high temperature and high pressure. This high temperature came from the Sun." and "Meteorites move around the Sun. They reflect the light from sun. So it is shining". Ms. Wong did not question students' statements immediately. Another student corrected the second statement. During the break, the author discussed the first statement with her and at the second session, she skillfully explained where the high temperature came from when the oil formed.

ASSERTION 7. The school climate and resources provided by the school can have a major impact on the development and performance of the teacher.

Observations and interviews indicated that Ms. Wong benefited from a well organized and well maintained school with strong school and instructional leaders. The school had administrators and department chairs that provided strong support; the science department chair, in particular, aided Ms. Wong in deciding how to teach science and how to work with young kids. She also received good help from other colleagues.

Interview data indicated there also was good parental involvement with the school and that parents expressed their concerns on what the school should do and what it had done.

V. Discussion / Related Literature

Several of the assertions identified variables commonly found in research of effective and successful school. These include the school climate, strong administrative and instructional leadership, a "caring" school staff, cooperative staff, the expectation that students can learn, and adequate time to learn (Northwest Regional Laboratory, 1990). The data obtained in this study indicated that the school provided an environment that helped Ms. Wong evolve as an effective teacher.

Ms. Wong's personal traits and characteristics were very influential in her performance with her pupils and in her improvement as a teacher. While some research studies indicate personal characteristics help to identify successful teachers (Balzer, Evans & Blosser, 1973), many studies, including meta-analyses studies (Druva & Anderson, 1983; Holdzkom & Lutz, 1984), frequently indicate they have low positive correlations, or are non-directional. From observations of this teacher and other teachers, the author has a strong feeling that personal traits and characteristics are important and probably would account for much more variance if properly assessed and documented. The lack of stronger relationships between teacher's performance and her/his personal traits/characteristics in quantitative studies may be due to a lack of focus and the use of high inference approaches that do not obtain data that represent the actual situation.

The importance of content knowledge to effective teaching has been the topic of many articles and research (Tobin & Fraser, 1989; Wittrock, 1986; Houston, 1990; Shulman, 1986; Grassman, *et al*., 1989). The data obtained in this study indicated teacher content knowledge had a substantial impact on the way the teacher planned instruction, the type of activities used, and teacher-student interaction. Observations indicated that alternative concepts went unchallenged when the teacher felt uncomfortable with the content.

In future research related to teacher content knowledge, more attention needs to be given to the ways teachers teach differently due to the lack of content knowledge, and the resulting effects on students.

Research on instructional strategies have yielded several practices that correlate with effective instruction (Holdzkom & Lutz, 1984; Wise & Okey, 1983). Ms. Wong exhibited many of these strategies. As a young teacher with four years of experience, she has developed successful instructional procedures. How did she grow from a novice teacher to an experienced teacher? How did she put theories that she learned in teacher college into practice? Both need further research.

VI. Conclusions and Recommendations

Assertions generated from this study supported the notion that Ms. Wong's science teaching has the following characteristics: (1) clear communication; (2) emphasis on stimulating students' thinking by questioning; (3) a quick mind and concern about students' learning; (4) classroom management that effectively attracts students' attention and motivates them to learn; (5) self-reflective thinking about her own teaching and making adjustments; (6) talent at creating a good learning climate; (7) a broad repertoire of teaching styles to involve students in learning.

Ms. Wong's personal traits, concern for students, preinstructional preparation, and continuous self-improvement made her perform well in science teaching. The school's strong leadership, resources, and supportive colleagues helped her development. The teacher's science knowledge influenced her/his teaching styles, questioning and student-teacher interactions in class.

The author strongly feels that Ms. Wong's teaching was mainly influenced by her personal traits. Can Ms. Wong's personal traits be learned? If her personal traits can be learned, how can they be taught to other teachers? If not, how can these traits be identified and what are good standards of these personal traits for recruiting new teachers? All these questions need further research.

How do we help other teachers to develop their skills as Ms. Wong has? How do we help "Ms. Wongs" to improve their content knowledge to strengthen their instruction and student learning? Both preservice and inservice teacher programs could provide more input to help improve school science teaching.

Some studies on specific units of study at the same grade level should be done to observe how teachers with differing content knowledge levels plan and teach students.

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Reference

Balzer, A. L., Evans, T. P. & Blosser, P. E. (1973). *A review of research on teacher behavior*. ERIC, Ohio State University.

Blosser, P. E. (1973). *Handbook of effective questioning techniques*. Educational Associates, Inc., Washington, Ohio.

Cobern, W. W. (1993). Contextual constructivism: The impact of on the learning and teaching of science. In Tobin, K. (Ed.) *The practice of constructivism in science education*. Washington DC: AAAS press, Chap.4.

Druva, C. A. & Anderson, R. D. (1983). Science teacher characteristics by teacher behavior and by student outcomes: A meta-analysis of research. *Journal of Research in Science Teaching*, *20*, 481-495.

Erickson, F. (1986). Qualitative methods in research on teaching. In Merlin C. Wittrock (Ed.) *Handbook of research on teaching*. New York: MacMillan Publishing Co., 119-161.

Flanders, N. A. (1962). *Teacher influence, pupil attitudes, and achievement*. University of Michigan, Ann Arbor, Michigan.

Grossman, P. L., Wilson, S. M. & Shulman, L. S. (1989). Teachers of substance: Subject matter knowledge for

teaching. In Reynolds, M. C. (Ed.) *Knowledge base for the beginning teacher*. New York: Pergamon press.

Helgeson, S. L., Suydam, M. N., Blosser, P. E., Obsbone, A. & Howe, R. W. (1977). *The status of pre-college science, mathematics and social science education: 1955-1975*. ED 153876, ED 153878, ED 153880.

Holdzkom, D. & Lutz, P. B. (1984). *Research within reach: Science education. Charleston, West Virginia*: The Appalachia Educational Laboratory, Inc.

Houston, R. W. (1990). *Handbook of research on teacher education*. New York: MacMillan Publishing Co.

Gallagher, J. J. (Ed.) (1991). Interpretive research in science education, *NARST Monograph*, No. 4., Kansas State University.

Mosston, M. & Ashworth, S. (1990). *The Spectrum of teaching styles: From command to discovery*. New York: Longman press.

Northwest Regional Educational Laboratory (1990). *Effective schooling practices: A research synthesis 1990 update*. Portland, Oregon: Northwest Regional Educational Laboratory.

Shulman, L. S. (1986). Those who understand knowledge growth in teaching. *Educational Researcher, 20*, 4-14.

Tobin, K. & Fraser, B. J. (1989). *Exemplary practice in science and mathematics education*. Curtin University of Technology, Perth Western Australia.

Walberg, H. J. *et al.* (1980). *A meta-analysis of productive factors in science learning grade 6-12*. Chicago, Ill., University of Illinois at Chicago Circle.

Wei, M. T. & Yang, R. S. (1988). *The survey of learning of fundamental science in senior high school*. Project report. National Taiwan Normal University, Science Education Center, Taipei. (In Chinese)

Weiss, I. R. (1978). *Report of the 1977 national survey of science, mathematics, and social studies education*. Center for Educational Research and Evaluation Research, Triangle Park, North Carolina.

Wise, D. C. & Okey, J. R. (1983). A meta-analysis of the effects of various science teaching strategies on achievement. *Journal of Research in Science Teaching, 20*, 419-435.

Wittrock, M. C. (1986). *Handbook of research on teaching*, third edition. New York: MacMillan Publishing Co.

以人種誌學的方法分析
一位國小科學教師的教學表現

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摘　要

本研究的目的以銓釋性研究法瞭解一位有經驗的國小科學敎師的教學。所觀察之個案敎師爲師專語文組畢業，且具有4年之學經驗。除實地觀察敎學外，同時錄影並訪談學校行政主管、敎師本人及其學生。研究結果發現敎師對科學的信念與其敎學具一致性。敎師對其所具之科學知識感到不自在時，將難於將其信念表現於實際敎學中。有經驗之老師及行政主管之協助，對於一位老師專業之成長是非常重要的。

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Cognitive Difficulties Related to The Understanding of Continuity

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ABSTRACT

The concept of function is very complex and has a number of concepts associated with it, such as domain, image, variable, one-to-one, onto, continuity, limit and so forth. Since all differentiable functions are necessarily continuous, the concept of continuity should not be overlooked in the teaching of calculus courses. Moreover, reading and interpreting graphs, sketching graphs of functions, and the transition from the concept of drawing a graph of discrete quantities to that of a continuous quantity are the most fundamental topics and central themes of the junior and senior high school mathematics curriculum in Taiwan. In practical work, the concept of continuity is important and necessary because it satisfies a very important property called the intermediate value property.

Although many researchers have studied the concept of function, little has been done that has addressed the connection between the "visual definition" and the limit definition of continuity. The research reported here was aimed at these two definitions of continuity associated with how frequently students take the concept from one setting and apply the same concept in a different setting. It is our intention to demonstrate the fact that students have great trouble in establishing appropriate links between these two definitions of continuity. Therefore, the purpose of the study is to collect information about the nature of the students' understanding of these two representations and attempt to reveal any cognitive obstacles which students may have.

Key words: visual definition of continuity, limit definition of continuity, cognitive obstacle

I. Introduction

During the past several years, there has been a considerable amount of research (Bergeron and Herscovics 1982; Breidenbach *et al.* 1992; Dreyfus & Eisenberg, 1982; Dubinsky & Harel, 1992; Janvier, 1982; Sfard, 1989, 1992; Sierpinska, 1992) concentrating on the understanding of function, both from epistemological and pedagogical points of view. The various reports have provided many useful sources for the development of the concept of function. In fact, the concept of function is very complex. It has a number of concepts associated with it, such as domain, image, variable, one-to-one, onto, continuity, limit and so forth. Since all differentiable functions are necessarily continuous, the concept of continuity should not be overlooked in the teaching of calculus courses.

Moreover, reading and interpreting graphs, and sketching graphs of functions in which the value of one variable depends on the value of another are the most fundamental topics in mathematics. But, unfortunately, Kerslake (1981) reported that many students found difficulty with the idea that there were any more points on the line other than those they had plotted. Some students think that there are no points between any two points they have already plotted, while others think that there is just one, presumably the mid-point. The transition from the concept of drawing a graph of discrete quantities to that of a continuous quantity is very important and it is also one of the central themes of the junior and senior high school mathematics curriculum in Taiwan (Yen & Law; 1993). In practical work, the concept of continuity is important and necessary because it satisfies a very important property called the intermediate value property. Also, if we find an interval on which a function changes sign, how can we guarantee that the function has a zero there?

What does it mean for a function to be continuous? Continuity is usually introduced in one or several of a variety of representations. Those representations include the "visual definition" of continuity, the limit definition of continuity, and the ε-δ definition of continuity.

Visually, a function is said to be continuous on an interval if its graph has no breaks, jumps, or holes in that interval. In other words, a continuous function has a graph which can be traced without lifting the pencil from the paper. Fischbein (1973) claimed that it was absolutely essential to encourage the use of intuitive support which could be understood and be built upon in a meaningful way by the students. Consequently, teachers should exploit student intuition and curricula should be modeled around such intuition, too. Indeed, what is intuitive to one person is not intuitive to another. It depends much on students' personal experiences. Moreover, intuition can also be misleading to students. Therefore, there is a need to first assess the basic intuition and experiences students have in common on continuity, and how frequently they solve problems on the basis of their intuition.

We say a function is continuous at a point, in the sense of notion of limit definition of continuity, when the limit of a function matches its output at that point. Alternatively, the limit definition of continuity can be defined as: f(x) is continuous at the point x = a if and only if the limit of f(x) equals f(a) when x tends to a. More explicitly, there are three requirements for a function f(x) to be continuous at the point x = a, namely (1) when x tends to a, the limit of f(x) must exist; (2) f(a) must be defined; and (3) these values must match.

Most college mathematics teachers would probably agree that students have insurmountable difficulties with the ε-δ definition of continuity. It turnsout the that ε-δ definition of continuity is neglected in their mathematics classes. Or they tend to use the visual approach which suggests that a function is continuous if its graph is unbroken or can be drawn without lifting the pen from the paper. Or they may provide the ε-δ definition of continuity and work with the limit definition of continuity for a short while. The answer of the question of whether it is necessary to teach the ε-δ definition of continuity in a beginning calculus course is beyond this study and has been discussed in Law's (1993) study. As a result, many students may have developed the concept of the "visual definition" and the limit definition of continuity only.

In most cases, mathematics educators think that there may be no major problem if students can successfully identify examples and non-examples of continuity. But researches (Tall & Vinner, 1981; Vinner, 1992) reported that many students still had misconceptions when they tried to explain the reasons why a function was continuous or discontinuous. The findings of cognitive difficulties related to the understanding of continuity in those studies are: (a) for a function to be continuous is the same as it being defined and for it to be discontinuous is the same as it being undefined at a certain point; (b) a function is continuous at a point x=a because it tends to a limit when x tends to a; (c) for a function to be continuous is the same as it being given by a single formula and for it to be discontinuous is the same as it being given by more than one single formula, such as piecewise defined functions.

Although many researchers have studied the concept of function, little has been done that has addressed the connection between the "visual definition" and the limit definition of continuity. The research reported here was aimed at these two definitions of continuity associated with how frequently students take the concept from one setting and apply the same concept in a different setting. It is our intention to state the fact that students have great trouble in establishing appropriate links between these two definitions of continuity. Therefore, the purpose of the study is to collect information about the nature of the students' understanding of these two representations and attempt to reveal any cognitive obstacles which students may have.

Ii. Methods

The concept of continuity is usually introduced in one or several of a variety of definitions, either simultaneously or in short succession. These definitions include the "visual definition", the limit definition, and the ε-δ definition of continuity. The question which then naturally arises is whether students establish appropriate links between these different definitions of continuity. Schoenfeld (1986) and Kaput (1982) showed how students who acquired knowledge in one representation kept it separate from knowledge acquired in other representations. However, many mathematics educators are not aware of the importance of bridging the gap between the "visual definition" and the limit definition of continuity. It is our purpose to reveal the fact that some students keep the concepts acquired from these two definitions separate and also lack the knowledge to give the reasons for continuity and discontinuity in reference to these two representations of the concept of continuity.

1. Subjects

The subjects involved in this research were chosen from two standard beginning calculus courses for engineering students at the Chinese Culture University in Taiwan. Those subjects were considered as below average in ability among engineering students in Taiwan universities based on their university entrance examination held by the government. A total of 82 students from these two classes taught by the author were in the study sample. They were told that the test would not have any impact on their course grade.

2. Questionnaires and procedures

A set of paper-and pencil tasks assessing the concept of continuity were designed and administered to the subjects. The questionnaire consisted of a systematic method of gathering information on the common difficulties students might have about the concept of continuity. It included three sets of questions (See Appendix). In the first set, the questions were given to the students as true-false questions . Most of them focused on the common misconceptions students might have. In the second set, the functions were given by means of graphs. Students needed to identify successfully whether those functions were continuous. Identifying whether those functions were continuous was not the main point of this study. We focussed on asking students to justify their answers. In this case, from a mathematical point of view, students have to apply the definitions to a specific case and to examine whether the conditions in the definitions hold or do not hold in this specific case. Moreover, we want to know whether students could find the limits of functions on different occasions. In order to identify any trouble students have in learning the concept of continuity in different settings, we designed the third set of questions, which were corresponding to the questions in the second set. In the third set, the functions were given algebraically and students were told to do the same tasks as in the second set of questions. These three sets of questions were administered simultaneously and the time to take the test was unlimited.

III. Results and discussion

First, we would like to report about the percentages (rounded to integers) of correct and incorrect answers to the first set of questions.

As shown in Table 1, there were 50% who thought that for a function to be continuous at a point x=a was the same as its limit existing at that point; 87% thought that for a function to be continuous at a point x=a was the same as its two one-sided limits both exist and match; 34% thought that for a function to be continuous at a point x=a was the same as it being defined at that point; 34% thought that for a function f to be continuous at a point x=a was the same as f(a) existing; 20% thought that for a function to be continuous at a point x=a was the same as its graph being unbroken at that point; 45% thought that for a function to be continuous at a point x=a is the same as the point (a, f(a)) being on the graph of that function; and 24% thought that for a function to be continuous was the same as that function being written as a single formula.

The percentage distribution of different responses in the second and third sets of questions are shown in Table 2.

Readers should not be misled by the percentages of successful identification of continuous and discontinuous since it cannot tell if students are really understanding the concept. We should em-

Table 1. The distribution of answers to the first set of questions (n = 82).

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Correct	50%	13%	66%	66%	80%	55%	76%
Incorrect	50%	87%	34%	34%	20%	45%	24%

Table 2. The distribution of responses to Q8 — Q16 (in percentage; n = 82)

	Question	8	9	10	11	12	13	14	15	16
cont.	the graph is unbroken	25						7	6	
	limit definition	4						5		
	limit exists	18		3	9	10	2	22	6	11
	f(a) is defined or exist	7	1	4		2	6	13		
	values at seam point match							12		
	other wrong reasons	5		2		12				24
	no explanation	11	1	2	3	6	4	11	4	16
dis-cont.	limit does not exist			12	11	4			10	
	left-hand limit ≠ right-hand limit	7	41	5	4		28			
	limit ≠ f(a)			8					5	
	f(a) is not defined or does not match		6	9	37	44				23
	the graph is broken		41	37	20	5	10	6		4
	it is not a smooth curve	16								
	values at seam point do not match						25	4	38	
	other wrong reasons						12	8	2	
	no explanation	5	9	18	15	11	12	4	23	10
	no response to the question	1			1	6	1	8	6	12
limit exists	correct limit	48		7	15	32		69	5	47
	f(a)		18	26			20			
	other wrong answer	2				10	6	1	34	9
	no answer	26	17	26	18					
	limit does not exist	22	63	39	65	45	68	18	50	28
	no response to the question	2	2	2	2	13	6	12	11	16

Underlining indicates the acceptable answer.

phasize the successful identification of continuous and discontinuous as well as the reasons why it holds.

From the above, we can see numerous common misconceptions and cognitive obstacles students have had, and we have tried to analyze them in detail. We say that the limit of a function exists if and only if the left-hand limit and right-hand limit both exist and are equal at a certain point. In most cases, we think that there is no major difference between them, but we have to face the fact that this is not the situation. It is obvious if we look at the percentages of the correct answers of Q1 and Q2. Furthermore, when we compared all students' responses to Q1 and Q2, we found 43% of students gave different answers. Also, we found more than 15% of students thought that the limit of a function at a particular point existed after they claimed the two one-sided limits at that point were not equal. It revealed that many students had the misconception that the existence of the limit of a function at a point x = a is not the same as the existence and equality of the left-hand limit and the right-hand limit of that function at that point. Many mathematics educators are not aware of the serious difficulty for students in realizing this cognitive conflict, or they totally ignore it when they teach the concept of limit. Therefore, as teachers, we must provide the connection by careful and detailed specification of the meaning of the concept of limit.

Moreover, it is hard to tell exactly why 87% students made mistakes in Q2, but I would like to suggest an explanation. I believe the reason is that students confused continuity with the concepts of limit. It is our intention to investigate the confusion between the concepts of limit and continuity that arose naturally in teaching the limit definition of continuity. As discussed before, when we teach the concept of continuity, we usually introduce its equivalent conditions, such as: (1) when x tends to a, the limit of f(x) must exist; (2) f(a) must be defined; and (3) these values must match each other. But in fact, many students can grasp only one of the first two conditions. For example, students may make the mistakes that limit existing infers continuity (50%) or f(a) being defined infers continuity (34%). Actually, it is the major mistake students have made in taking the test. Further investigation of students' responses also found other misconceptions, such as many students thinking that discontinuity infers limit not existing and f(a) not defined infers limit not existing.

When you visualize a graph of unbroken curve, you may know that it is continuous. Knowing this does not mean understanding of the concept. Also, knowing this does not mean being able to use it to solve problems. Although we have 80% of students conscious of the "visual definition" of continuity and there is no doubt that this definition is the essential and most efficient way to explain whether a function is continuous in a graphic setting, we have less than half of the students (25%, 41%, 37% and 20% in the second set of questions respectively) using it correctly to solve the problems.

In the graphic setting, most of the students tried to make use of the limit definition of continuity as their explanation, but many of them failed. On the contrary, just a few students used the "visual definition" to justify their answers in the algebraic setting. This indicates that students have great trouble in establishing appropriate links between these two definitions of continuity. It is usually hoped that students having mastered the continuity concept in one setting will be able to transfer it to other settings. But this study shows that the passage between these representations is difficult and such transfers of learning take place only if the settings are sufficiently similar.

Some students would insist that a function should be given by one rule of correspondence or a single curve. If two rules or more are given for disjointed domains, then they are dealing with two functions or more. Moreover, if one of the domains is a singleton, then it is not considered as belonging to the function. This phenomenon has also been observed by this study.

Quite predictably, we also noticed that students have more difficulty finding the limit of functions in terms of graphs than in terms of algebraic expression. Moreover, the proportion of students who can find the limit is much lower. Especially for the piecewise defined functions, many students claimed that the limit equals the value of the function at that point no matter whether the function is continuous or not. It turns out that if f(a) is not defined or does not exist then the limit of f at the point a does not exist. It also revealed that students grasped the technique-and-formula conception of limit. Is this all that we want? We believe that the answer is definitely "No" (Law, 1994). Although many students can plug the value a into different pieces of a piecewise defined function in order to check whether the limit exists or not, most of them do not know why it works. They just follow the rule that if the values of a function f at the seam point a match each other then the value of the limit is f(a). What happens if they are not matched? It shows again that knowing the technique-and formula does not mean understanding. We have support from the responses to Q15.

IV. Conclusions

This study presented several main points from the perspective of cognitive difficulties related to the understanding of continuity.

(1) When we look at the data obtained from the second and third sets of questions in detail, we find that they are not consistent with those from the first set of questions. Our explanation is that students doing mathematics often use different concept images according to the different representations, and make different errors depending on the problem under consideration. It seems that they simply utilize the concept images they consider appropriate and they cannot see any cognitive conflict in their responses.

(2) The most impressive aspect of the data is the high percentage of students (71%, 98%, 89%, 89%, 64%, 87%, 70%, 78%, and 37% respectively) who can identify examples and non-examples of continuity, but not all of them (only 29%, 82%, 45%, 57%, 49%, 53%, 24%, 43%, and 27% respectively) know the reasons. It reveals the situation that students do not necessarily use the definition when deciding whether a given function is continuous or not. In most cases, they decide on the basis of their intuition and then try to find something they think is fitting to explain how it works.

(3) Although investigation into university students' conceptions of continuity has revealed numerous common misconceptions and cognitive ob-

stacles, the most serious problem we faced shortly after introducing the concept of continuity is that many of our students seem to be lacking the ability to analyze and manipulate the concept with a confidence which can only be achieved by those who can treat it as if it were a real thing. Therefore, we need further study to uncover more unknown cognitive and social difficulties and develop a new approach to coping with these problems in teaching.

Appendix

A. True -false questions:

Q1 If the limit of a function at a point x = a exists, then the function is continuous at that point.

Q2 If the left-hand limit and the right -hand limit of a function at a point x = a exist and are equal, then the function is continuous at that point.

Q3 If a function is defined at a point x = a, then the function is continuous at that point.

Q4 If f(a) exists, then the function f(x) is continuous at the point x = a.

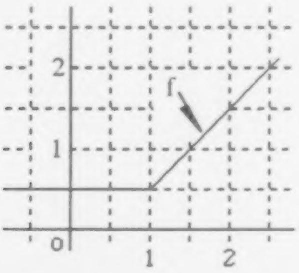
Q5 If the graph of a function is not broken at a point x = a, then the function is continuous at that point.

Q6 If (a, f(a)) is on the graph of the function f(x), then the function is continuous at the point x = a.

Q7 If a function can be written as a single formula, then the function is continuous.

B. Answer the following questions:

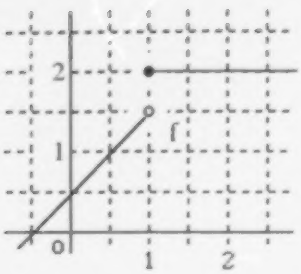
Q8



a. Is the function f in the above figure continuous at x = 1? Explain.

b. Does $\lim_{x \to 1} f(x)$ exist? If so, please find the answer.

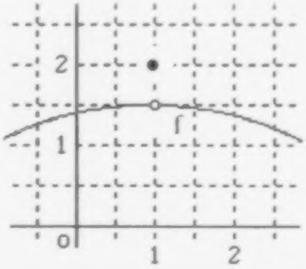
Q9



a. Is the function f in the above figure continuous at x = 1? Explain.

b. Does $\lim_{x \to 1} f(x)$ exist? If so, please find the answer.

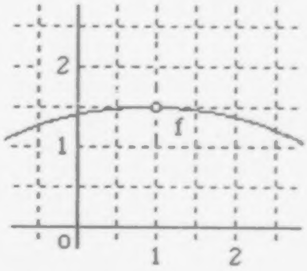
Q10



a. Is the function f in the above figure continuous at x = 1? Explain.

b. Does $\lim_{x \to 1} f(x)$ exist? If so, please find the answer.

Q11



a. Is the function f in the above figure continuous at x = 1? Explain.

b. Does $\lim_{x \to 1} f(x)$ exist? If so, please find the answer.

C. Answer the following questions:

Q12 $g(x)=x^3-8$ if $x \neq 5$

a. Is the function g above continuous at $x = 5$? Explain.

b. Does $\lim_{x \to 5} g(x)$ exist? If so, please find the answer.

Q13 $$g(x)=\begin{cases} 2x+3 & x>5 \\ x+5 & x\leq 5 \end{cases}$$

a. Is the function g above continuous at $x = 5$? Explain.

b. Does $\lim_{x \to 5} g(x)$ exist? If so, please find the answer.

Q14 $$g(x)=\begin{cases} 2x+1 & x\geq 5 \\ 3x-4 & x<5 \end{cases}$$

a. Is the function g above continuous at $x = 5$? Explain.

b. Does $\lim_{x \to 5} g(x)$ exist? If so, please find the answer.

Q15 $$g(x)=\begin{cases} 4x-3 & x\neq 5 \\ 15 & x=5 \end{cases}$$

a. Is the function g above continuous at $x = 5$? Explain.

b. Does $\lim_{x \to 5} g(x)$ exist? If so, please find the answer.

Q16 $$g(x)=\frac{x^3-5x^2+x-5}{x-5}$$

a. Is the function g above continuous at $x = 5$? Explain.

b. Does $\lim_{x \to 5} g(x)$ exist? If so, please find the answer.

References

Bergeron, J. , & Herscovics, H. (1982). Levels in understanding of the function concept. *In Proceedings of the Workshop on functions*, organized by the Foundation for Curriculum Development. Enschede: The Netherlands.

Breidenbach, D., Dubinsky, E., Hawks, J., & Nichols, D. (1992). Development of the process conception of function. *Educational Studies in Mathematics, 23*, 247-28.

Dreyfus, T. , & Eisenberg, T. (1982). Intuitive functional concepts: A baseline study on intuition. *Journal for Research in Mathematics Education, 1*(5), 360-380.

Dubinsky, E. & Harel, G. (1992). The nature of the process conception of function. In E. Dubinsky &G. Harel (Ed.), *The concept of function: aspects of epistemology and pedagogy* (MAA Notes Vol. 25, pp. 85-106). Washington DC: Mathematical Association of America.

Fischbein, E. (1973). Intuition, structure, and heuristic methods in the teaching of mathematics. In A. G. Howson (Ed.). *Developments in mathematical education*. Cambridge: Cambridge University Press.

Janvier, C. (1982). Approach to the notion of function in relation to set theory. *Proceedings of the Workshop on functions*, organized by the Foundation for Curriculum Development. Enschede: The Netherlands.

Kaput, J. (1982). Intuitive attempts at algebraic representation of quantitative relationships. *Paper presented at the annual meeting of the American Educational research Association*. New York.

Kerslake, D. (1981). Graphs. In J. Murray (Ed.), *Children's understanding of Mathematics: 11-16* (pp. 120-136). London: The CSMS Mathematics Team.

Law, C. K. (1993). Learning the ε-δ definition of continuity. In *Proceedings of the technology in Mathematics Teaching Conference*, pp. 312-320. United Kingdom: Birmingham.

Law, C. K. (1994). The role of programming in teaching calculus. In *Proceedings of the 7th annual international conference on technology in collegiate Mathematics*. USA: Florida.

Schoenfeld, A. (1986). On having and using geometric knowledge. *In Conceptual and Procedural Knowledge: The Case of Mathematics*. J. Hiebert (ed.) . 225-264.

Sfrad, A. (1989). Transition from operational to structural conception: the notion of function revisited. In Gerard Vergnard (Ed.), *In proceedings of the Thirteenth International Conference for the Psychology of Mathematics Education*, Paris, France.

Sfrad, A. (1992). Operational origins of mathematical objects and the quandary of reification—The case of function. In E. Dubinsky &G. Harel (Ed.), *The concept of function: aspects of epistemology and pedagogy* (MAA Notes Vol. 25, pp. 59-84). Washington DC: Mathematical Association of America.

Sierpinska, A. (1992). On understanding the notion of function. In E. Dubinsky &G. Harel (Ed.), *The concept of function: aspects of epistemology and pedagogy* (MAA Notes Vol. 25, pp. 25-58). Washington DC: Mathematical Association of America.

Tall, T. & Vinner, S. (1981). Concept image and concept definition in mathematics with particular reference to limits and continuity. *Educational Studies in Mathematics, 12*, 151-169.

Vinner, S. (1992). The function concept as a prototype for problems in mathematics learning. In E. Dubinsky &G. Harel (Ed.), *The concept of function: aspects of epistemology and pedagogy* (MAA Notes Vol. 25, pp. 195-213). Washington DC: Mathematical Association of America.

Yen, C. L. , & Law, C. K. (1993). *Cognitive development of the concepts of linear function and quadratic function for junior high school students in Taiwan* . Proceedings of the National Science Council, *3*(2), 43-54. Republic of China.

瞭解連續概念之認知障礙

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摘　要

函數是一十分複雜的數學概念，如定義域、函數值、變數、一對一、映成、連續、極限等等概念。因可微函數皆連續，故此，在初等微積分課程中，連續概念不應被輕視。再者，讀圖、解圖、描繪函數圖形、以及如何從點而線的繪圖概念皆爲我國中等數學教育課程中極爲重要的課題。實際上，連續概念的必要性在中間値定理上表露無遺。

雖然很多學者從事有關函數概念的研究，但對連續概念的「圖形定義」和極限定義的研究卻是不多，尤其對此兩種連續定義之關連性的研究更是少之又少。故此，本研究特別針對此兩種連續定義作探討，並且嘗試瞭解學生在不同的數學情境中，交替使用此兩種連續定義次數的情形。再者，本研究的主要目的在於揭露出學生對此兩種連續定義之間學習轉移存有極大的困難。因此，本研究欲透過資料的蒐集，來探索學生對此兩種連續定義之瞭解情況，同時希望能發現學習此兩種連續定義之認知障礙，藉以達到本研究的最終目的。

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On the Development of an Intelligent CAI for Chemistry Courses*

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ABSTRACT

In the filed of CAI, the system's capability to adapt tutoring processes to individual students is very limited, and hence these instructional systems have difficulty in providing robust and rich learning environments. Starting in the 1970s, Intelligent CAI(ICAI) systems were discussed in order to overcome the limitations of traditional CAIs by imposing Artificial Intelligence (AI) principles and techniques on conventional approaches. The ICAI system can instruct students in an intelligent way, and bring more interaction and flexibility to the domain of tutoring. In this paper, we propose an ICAI system in the domain of senior high school chemistry courses. The system provides a flexible learning environment to assist in instructional activities by taking students' behaviors and personalities into account. Moreover, a management system is offered to help the teacher understand the status of each student, and to assist the ICAI system in constructing a personalized tutoring program.

Key words: artificial intelligence, computer assisted instructions, expert systems, chemistry courses

I. Introduction

With the advent of low-cost microcomputers, computer applications in education are expanding rapidly. Many computer-assisted instruction (CAI) systems have been developed and even marketed, with the purpose of using computers to assist in instructional activities. It may not be known that the earliest computer-based educational applications were developed on mainframes and minicomputers, of which two of the best-known systems are PLATO (on a mainframe system) and TICCIT (on a minicomputer system). PLATO was developed at the Illinois University in 1959, and TICCIT in 1971 with the combined efforts of the engineers from MITRE Corporation and educators from Texas University. Before the introduction of microcomputers, instructional applications were restricted to large projects that had the funds necessary for expensive computers. In 1977, however, some microcomputers were proven to be successful in this field. And hence it become possible for the individual researchers at universities, and even the teachers at small schools, to utilize the computer for educational purposes [13] [15]. The emergence of

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readily available microcomputers at a much lower cost has furthered the growth and popularity of CAI.

Although there has been notable success in CAI domain, the construction of CAI systems has been inadequate in providing the "robust and rich" learning environment. Since the instructional process had to be specified in the program before being used in instruction, the system's capability to adapt tutoring processes to individual students was very limited [11].

Owing to the varied personalities of human beings, an experienced teacher would present subject materials while considering the capabilities and behaviors of the students. Therefore, in developing an ICAI system, the personal features of the student have to be taken into consideration in order to properly manage tutoring processes [1] [3] [4] [9] [10] [12]. In our ICAI development, we not only focus on the design of user interfaces and subject materials, but also pay attention to the analysis of personalities. By analyzing the personal characteristics, the system is also to present more flexible and personalized tutoring processes for a variety of students. We also developed a management system to help the teacher to evaluate the status of each student, and to assist the ICAI system in constructing a personalized tutoring program.

II. Reviews of Previous Work

ICAI research has been going on for more than twenty years, and a number of impressive programs have been built and demonstrated. It is an example of the application of artificial intelligence technology in the field of instruction. IN 1970, Carbonell's SCHOLAR system, used to teach South American geography, served as an impetus for the development of ICAI systems. At first, it attempts to diagnose the student's misconceptions and then presents materials that will force the student to see his or her errors by the Socratic method of tutorial dialogue. SCHOLAR was then extended by the WHY system, which instructs students about the causes of rainfall.

The SOPHIE system was an attempt to create a "reactive learning environment", in which students acquire problem-solving skills by trying out their own ideas rather than by receiving instruction from the system. It allows students to have a one-on-one relationship with a computer-based expert who helps them come up with their own ideas, experiment with these ideas and modify them when necessary. The principles of SOPHIE have been applied in the construction of a diagnostic model, referred to as BUGGY, for learning basic mathematical skills. It provides a mechanism for explaining why a student is making a mistake, as opposed to simply identifying the mistake.

WEST is a coaching program designed to teach the manipulation of arithmetic expressions in a computer game environment. The coaching model is used to identify diagnostic strategies required to infer a student's misunderstandings from observation of the student's performance and to provide advice that will improve the student's performance. It is best suited to problem-solving types of programs, e.g., simulations and games. With the help of AI techniques, the research group of WEST also develops a proof checker, EXCHECK, capable of understanding the validity of a student's proof.

Many different types of applications appeared in the history of ICAI development, including tutors for mathematics, diagnostic tutors for computer languages, intelligent simulations, etc. This reflects the diversity of ICAI perspectives and the relatively little homogeneity in the ICAI field. There are major differences in the research goals and theoretical frameworks among ICAI research projects. In the current ICAI domain, there have been several different design paradigms such as coaches, diagnostic tutors, etc. Each paradigm deals with a specific set of issues and disregards others. No paradigm can cover all ICAI concerns since too little is known about the nature of teaching and learning to be able to provide domain-independent methods across all domains. Hence, the structure of an ICAI program emerges from the problem it is designed around the approach for developing ICAI is usually designed depending upon the tutorial domains.

III. An Expert System-Based Framework for ICAI Design

The function of ICAI is to convey knowledge about a subject matter area to a learner in an "intelligently" manner. In the history of ICAI development, a variety of methodologies have been proposed in order to achieve this instructional goal. Generally speaking, those modeling methods can be classified into several preordains and it can be concluded at this time that no paradigm is complete enough to cover all concerns dealing with the educational issues. Despite this fact, there have been many systems which are notable in their corresponding instructional domains. Therefore, the methodologies for developing ICAI are usually designed according to their tutorial domain, i.e., what the tutoring system wants to provide to the learners.

In this section, we first describe the tutoring domain and design goals of our ICAI system. And then based upon Expert System principles, a theoretical framework is proposed in accordance with our system domain.

3.1. Design goals

In our work, we wanted to offer another learning environment outside of the classroom, to assist in the pedagogical activities for a senior high school level Chemistry course. It should be noted that the emphasis of our system is to provide a supplemental method for students' learning, not to replace the teacher's work. In other words, it is an alternative instructional resource to human tutors in the school. Usually computer-assisted instruction will appeal to students by attractively displaying the subject materials, helping to motivate those students who do not have that much interest in the course. If one well-constructed ICAI system exists, it would seem to act as a tutor offering one-on-one instruction for many students. This function could provide another new instructional method, different from the traditional type of education in schools. In order to make our system more than just a "programmed textbook", but also capable of intelligently adapting a flexible tutorial process for individual students like a human tutor, artificial intelligence principles and techniques are applied to this design.

3.2. System Architecture

Owing to the different personalities of human beings, an experienced teacher would present subject materials by considering the capabilities and behavior of the students. Correspondingly, the learning processes suitable for the students are not all the same, since they usually possess different personal features from each other. Therefore, to make the system behave more intelligently and not merely present specified subject matters to students, *teaching* and *learning* have to be modeled. Some personal features of the student must be considered to properly manage the personalized tutoring process based on the teacher's experience. On our design, the system has to emulate the decision-making ability of human experts. To achieve this goal, Expert System technology was a good choice for modeling ICAI [5] [6] [14]; note our [CA] model shown in Figure 1.

In this framework, three major components are included–knowledge base, inference engine, and user interface. *Knowledge base* contains the knowledge necessary in the system, including teaching expertise, subject material, student model and diagnostic model. First, the inference engine determines the tutoring process for one student based upon the information in student's model and the teaching expertise, and then presents the corresponding subject content to the student. The system is able to generate a personalized teaching script for the student according to the expert's recommendation. The objective of this approach is to present the curriculum to the student in the most suitable way. After the learner has finished a given unit with its corresponding test problems, the system will evaluate the test results to obtain the new learning status using the diagnostic model. The new information will be recorded to generate the teaching script for the next tutoring session.

In the following, we will explain each part of the knowledge base in detail: The teaching expertise refers to the expert knowledge or experience

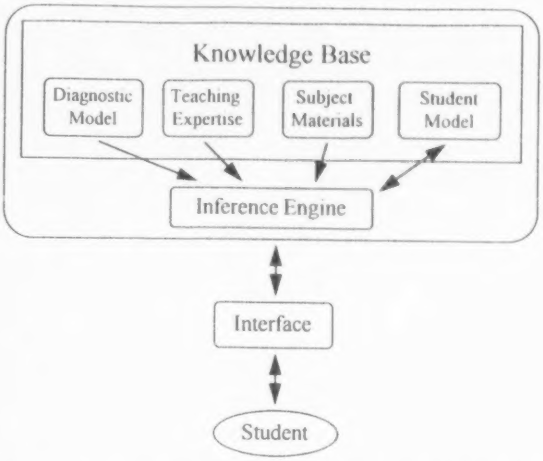


Fig. 1. A knowledge-based structure of an ICAI system.

concerning the determination of the tutoring process for different students. Obviously, the knowledge requirement is closely related to the structure of the model used to record the student's learning status. Therefore, before extracting teaching expertise, the definition of the student model in our ICAI should be determined first.

The student model is used to model the essence of learning, and is regarded as as the base for determining the tutoring process. Computer systems can only obtain the users' conditions through interaction with the users, hence an ICAI system needs to present some test problems to the student to acquire some personal information. However, this kind of interaction only helps to ascertain the student's level of ability. Since there are many factors which can influence the tutoring process, it seems subjective and inadvisable to build a student model and produce the teaching script by judging solely on the student's level of ability. In our approach, the student model, which is defined by consulting the expert, consists of two submodules:

1. Idiosyncrasy

There are many personal features which may influence the tutoring process. In our approach, five major factors were selected by the experts, including *Knowledge Level, IQ, Degree of Endurance, Degree of Concentration*, and *Degree of Willingness*. These features are represented in predefined degrees, such as *good, average* and *poor*.

2. History

This contains the information of each student's historical records, such as the units learned and the corresponding performance on those units.

The five factors above would influence the student's learning and could be applied to determine the teaching script based on teaching expertise, which is provided by the expert after building the student model. This concept would promote the personalization in the determination of the tutoring process. Hence, the student model is an essential component in the instructional system to achieve our set goals.

The subject materials are encoded by system designers according to the information elicited from experts or textbooks [2] [7]. For convenience and effectiveness in the selection/sequencing of the material, i.e., the creation of teaching scripts, a *frame* approach is used. The subject matter is organized into many microscopic units and each unit is called a frame, characteristically one screen in size. Each frame contains instructions or test problems. According to the expert's experience, students with different degrees of ability need teaching scripts presented in a variety of levels. Therefore, in our system, some different versions of the subject content have to be incorporated to provide students with proper tutorial processes.

The diagnostic model is used to assess the student's performance as well as mental state, for example, the degree of concentration. The modeling method is related to the type of test problems since it will influence the form of students' responses, these being the target information for diagnosis. The manner in which test problems are presented are also correlative with the user interface design. For the convenience of the users' operation and the recognition of students' responses, *multiple-choice tests* were adopted for our system. After assessing the student's performance, the system has to send the new learning status back to the student model and provide *feedback* to the student, which shows whether the student passed or failed. In addition to the diagnostic process, some strategies or parameters also need to be defined in this model, e.g., when to give feedback to the students, what is the content of a feedback, what is the standard for the students to pass a unit, etc.

3.3 A revised construction

As mentioned in the previous section, the tutoring process is determined by using both the teaching expertise and the information in the student model. However, if a student is using the CAI for the first time, the system holds no information concerning that student. In this case, the system will have no basis to determine the proper teaching script, so it can only determine the tutoring process for the student by employing a default sequence which might be inaccurate. Therefore, it would be better to ask teachers to provide some initial information concerning every student. In other words, the system obtains the information on the student's personality from the teacher to preset the tutoring sequence. Although this information does not need to be completely accurate, the approach helps the CAI system properly control the tutoring process.

To achieve this approach, a *management system* is needed to help the teacher offer student records and to maintain them in the student model. When a student uses the CAI system for the first time, the records concerning this student offered by the teacher will be employed to decide which teaching script of subject materials will be presented. After a student has finished one unit of subject material and the corresponding test problems, the system will evaluate his performance to determine a new learning status. The information will be added to the student model to update the base of the decision-making system. Teacher could also examine the difference between the new learning status and the initial one for reference. Therefore, the communication between the management system and the teacher is two-way. The CAI system receives help from a teacher in collecting the information on the students' personalities as well as gives some advise or information to help the teacher in evaluating and guiding the students. The new structure of the ICAI system is depicted in Figure 2.

The outward control procedures of our ICAI system can be summarized as follows:

1. Obtain the learning status of the student from the student model, including the information concerning the five personal features and history, and then generate a proper teaching script based on the teaching expertise and this information.
2. Present subject contents.
3. Display some test problems and get answers from the learner.
4. Diagnose the test result and mental state of the learner to obtain a new learning status.
5. Modify the information in the student model to reflect the current status of the learner.
6. Return to Step 1 until all of the curriculums have been mastered by the learner.

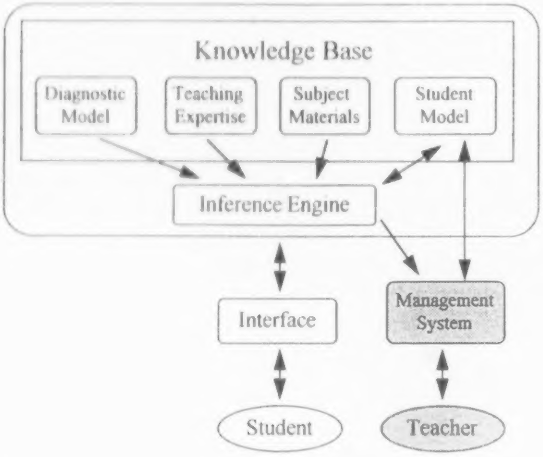


Fig. 2. A new structure of an ICAI system.

In the control procedures, it can be seen that there are still two issues unsolved in our ICAI development—the generation of the personalized teaching script and the diagnostic method for obtaining the student's status. Both strategies have to be defined according to the expert's recommendation. Regarding the determination of teaching scripts from the system designer's point of view, it is not efficient to design different versions of teaching scripts to cover all combinations of the personalities defined in the student model. In the next section, some methodologies will be proposed to cope with these problems, and the details about the management system will also be shown.

IV. Some Methodologies in Our Approach

4.1 A heuristic strategy for determining the tutoring process

In our design, the teaching expertise used to determine the tutoring process has to be elicited from the experienced teacher, and then be converted to a set of regularities stored in the knowledge base. The system will consider the characteristics and history of the learner to generate a personalized teaching script according to this pre-defined strategy. If a static analysis method is applied in the process of knowledge acquisition, all combinations of the five personal features defined in the student model have to be considered to manage those corresponding teaching scripts. It would be an excruciatingly difficult task for both the expert and the system designer.

For convenience and effectiveness in determining the tutoring processes, subject materials are divided into two categories:

1. Formal subject materials

These subject materials represent curriculums, i.e., chemistry. Several versions of presentation for varying levels are offered to achieve our design goals. Each version is determined by two factors—*Knowledge Level* and *IQ*.

2. Assistant subject materials

In addition to formal subject materials, some secondary ones are designed to assist in the instruction, used to emulate the tutorial activities of a human tutor. Such contents are used to overcome students' weak points like distraction, and to improve the effects of learning. For the other three features, *concentration*, *endurance* and *willingness*, three corresponding sets of assistant materials were developed in advance. The design principles are described in the Appendix.

In our approach, the teaching script can be determined dynamically in accordance with the personal features of the student. First, in our design, the version of the formal subject material is selected by considering the student's knowledge level and IQ. The selection is dependent upon following rules:

LEVEL (good) → 1
LEVEL (average) → 2
LEVEL (poor) → 3
IQ (good) → 1
IQ (average) → 2
IQ (poor) → 3

To select a suitable formal subject material we have VERSION=MAX (LEVEL, IQ).

For example:

MAX(LEVEL(good),
IQ(good))=MAX(1, 1)=1,
MAX(LEVEL(average),
IQ(good))=MAX(2, 1)=2,
MAX(LEVEL(poor),
IQ(average))=MAX(3, 2)=3.

It can be seen that the rules are more reserved. If the student's Level and IQ are not the same, the easier version is presented. The overall selection table is given in Table 1. After deciding on the formal subject material, a rough teaching script is generated.

Table 1. The Table to Select the Version of Formal Subject Materials

Knowledge Level	IQ	Version
good	good	1
good	average	2
good	poor	3
average	good	2
average	average	2
average	poor	3
poor	good	3
poor	average	3
poor	poor	3

Second, the system will individually examine the rest of the characteristics in the student model. According to the level of the feature, a proper number of the corresponding assistant subject materials will be selected using the following principles:

1. For concentration

Assume that T is the number of frames in a unit. For each frame, an assistant frame for concentration is presented according to a corresponding flag. Let S be the number of flags to be set to 'yes'. We have

degree: poor $S=T$
degree: average $S=\frac{2T}{3}$
degree: good $S=\frac{T}{3}$

That is, S assistant frames for concentration will be appended to the corresponding formal frames to make the students pay more attention to the CAI.

2. For willingness

degree: poor Select one frame concerning willingness from the assistant subject materials.
degree: average Determine randomly whether the frame for willingness is to be presented or not. The probability of 'yes' is 0.68.
degree: good Determine randomly whether the frame for willingness is to be presented or not. The probability of 'yes' is 0.32.

The selected frame for willingness is inserted in front of the formal subject material to make the CAI being more attractive.

3. For endurance

The same principle is applied to the determination of the frame for endurance, except that the selected frame is appended to the end of the formal subject material.

Consider the example in Figure 3, a student with average knowledge level, average IQ, poor degree of endurance, average degree of concentration and poor degree of willingness. The system first selects a suitable version of formal subject materials by considering the student's knowledge level and IQ; that is, MAX(LEVEL(average), IQ(average))=NAX(2, 2)=2. Therefore, Version 2 is selected, which consists of six frames of subject contents (F_1, F_2, F_3, F_4, F_5 and F_6). Later, the other three personal features in the student model, i.e., con-centration, willingness, and endurance, are analyzed, and the corresponding assistant subject material are selected respectively according to the degree of these features. For concentration, we use T=6 and $S=\frac{2T}{3}=4$; therefore, the system randomly selects four assistant frames for concentration (i.e., C_1, C_3, C_4, C_5) and appends them to the corresponding formal frames (i.e., F_1, F_3, F_4, F_5). Since the degree of endurance is poor, a frame for endurance is appended to the end of the formal subject material. Moreover, a frame for willingness is inserted to the front of the formal subject-material for the same reason. The final teaching script is also depicted in Figure 3.

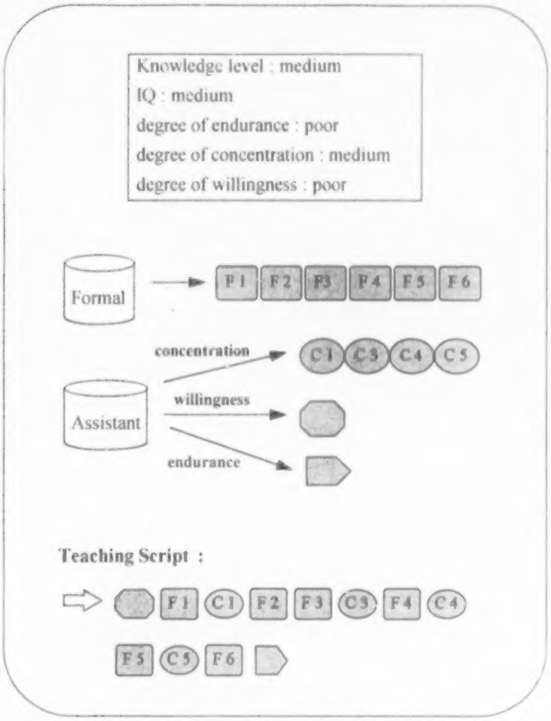


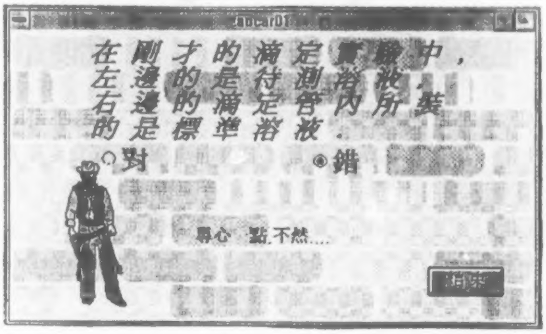
Fig. 3. An example describing the concept of our strategy.

Using this strategy, teaching scripts can be generated dynamically, not statically designed in advance to cover all combinations of the students' personalities. For system designers, it reduces the amount of information analysis and knowledge acquisition. This seems to be more convenient and effective in the design of the inference processor than by using the static analysis method.

4.2 The diagnostic model

The functions of the diagnostic model are to assess the student's performance and to diagnose his/her mental state. In the field of assessing students' performance, *Hsaio's evaluation model* [8] is applied after the unit test has been finished. From the result of this assessment, the system can obtain the level of the student's knowledge.

In regards to the diagnostic method of mental states, it is related to the design of assistant subject materials because we do the analysis according to the student's responses when he/she is given some assistant matters. Consider Figure 4, for example, it is one frame of the assistant subject materials for the feature 'Concentration'. It shows that the system asks the student one very simple question concerning about the content presented. The system can judge the student's mental state


在剛才的滴定實驗中，左邊的是待測溶液，右邊的滴定管內所裝的是標準溶液。

○對 ●錯

專心一點,不然....

Fig. 4. An assistant subject frames for concentration, which asks the students what have been presented in the last frame.

concerning this feature based upon his answer. The diagnostic principles concerning mental states are given as follows:

1. Feature concentraion

S: the number of frames in which the student gives the right answers for the corresponding questions

T: the number of frames offered to the student for this feature

Doc: degree of concentration

$R= \frac{S}{T}$

if $R<=\frac{1}{3}$ then Doc=poor

if $R>\frac{1}{3}$ and $R<\frac{2}{3}$ then Doc=average

if $R>=\frac{2}{3}$ then =good

2. Feature *endurance*

Detect the time that the student takes to learn one frame of formal subject contents. If the time is lower than a predefined value, then the degree of endurance has diminished.

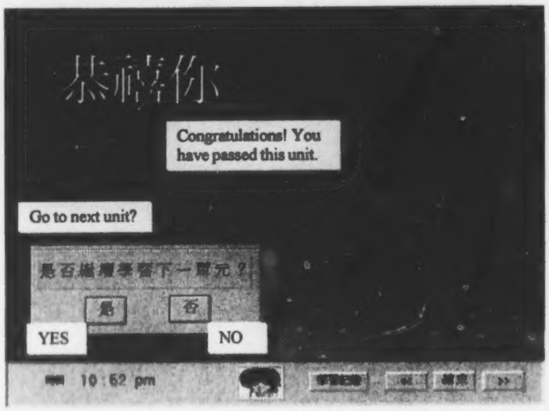
3. Feature willingness

Similar to the process in Feature *Willingness*. If the time is higher than a predefined value, then the degree of willingness has diminished.

In addition to the diagnostic task, the diagnostic model also gives some feedback to show the results of the test. In our system, a feedback frame is presented after the student has finished the unit test. If the student does not pass the unit, the system displays one feedback frame to reflect the test results instead of giving him (or her) the answers directly. The diagnostic model also records the new learning status of the student for future reference. With this new information, the system will be able to construct a new teaching script for the same unit taking into consideration the student's personal status and needs. The student is then asked to repeat the study of that unit. If the student has passed the subject unit, the system gives him/her the solutions for the incorrect answers as well as the 'passed' feedback frame illustrated in Figure 5.

4.3 The management system

In Section 3.3, the concept of the management system was introduced to deal with the problem when the ICAI system holds no information concerning the student because he/she is using the system for the first time. It offers two major functions—Append and Query, as illustrated in Figure 6. In addition to providing a user friendly interface for teachers to enter the students' initial information, the management system is able to maintain the database of the student model, including both the initial and new learning states of the student. By use of the "query operation" the teacher can compare these two sets of information for reference, and monitor the course proceeding and the corresponding performance of all the students in the management system. In other words, the management system is a bridge between the ICAI system and the teacher, offering two-way communication. Figure 7 shows the results of the query-



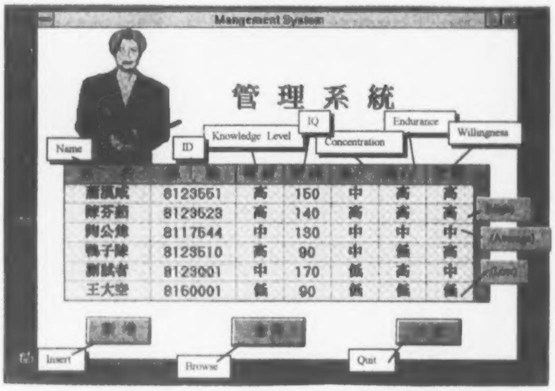
恭禧你

Congratulations! You have passed this unit.

Go to next unit?

是否繼續學習下一單元？

Fig. 5. One feedback frame which shows 'Congratulations, you have passed this unit'.



[illegible]	8123551	高	150	中	高	高
[illegible]	8123523	高	140	高	高	高
[illegible]	8117544	中	130	中	中	中
[illegible]	8123510	高	90	中	低	高
[illegible]	8123001	中	170	低	高	中
王大[illegible]	8150001	低	90	低	低	低

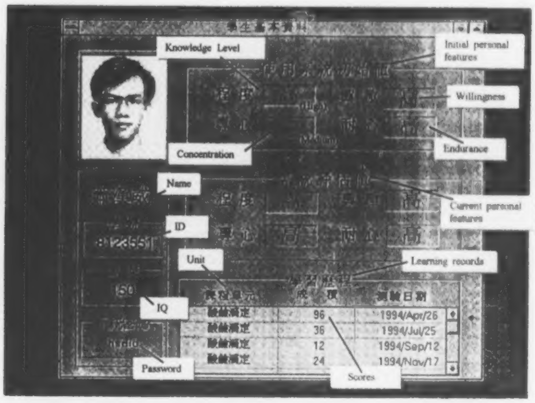
Fig. 6. Themain screen of the management system. In each row of the table, there are student's student ID, knowledge level, IQ, concentration degree, edurance degree and willingness degree respectively.

process made by the teacher, including both the initial and new learning states, the course proceeding, and the corresponding scores concerning the student.

It can be seen that our ICAI system is suitable to work in a network environment.

The tutoring processes are generated according to the information stored in the database of the student model; therefore the students have to use the same machine every time for the information to be available if the system is not installed on a network. For teachers, it would be convenient to monitor the learning states of the student if a network environment is available.

As a result, it would be better to build our system on a local area network as shown in Figure 8. The database of the student model is maintained in the server machine which is used by the teacher; the instructional systems are on the client machines used by students which can access the corresponding information concerning the user from the server to generate proper teaching scripts. In addition, the subject materials can be stored only in the server, not in the client machines, and can be accessed by these individual instructional systems whenever needed. This helps in the modification and maintenance of the subject matters and saves storage space on all of the machines.



[illegible]	[illegible]	[illegible]
[illegible]	96	1994/Apr/26
[illegible]	36	1994/Jul/25
[illegible]	12	1994/Sep/12
[illegible]	24	1994/Nov/17

Fig. 7. Thedetail of a student's records in the management system.

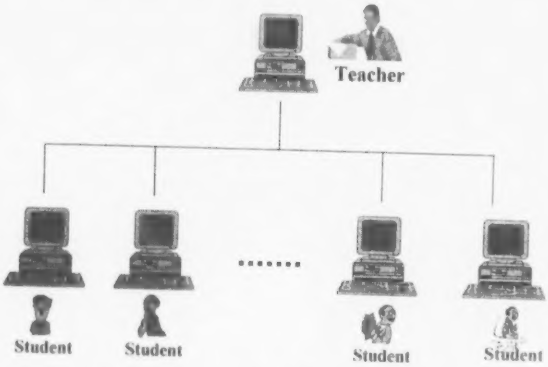


Fig. 8. The concept of ICAI on a local area network.

V. Conclusion

ICAI is an application area of artificial intelligence technology for instructional activities. In this paper, we propose a theoretical framework and some methodologies for the development of an ICAI system. In our design, the system can adapt personalized tutoring processes to the student for achieving instruction in a flexible way. With the help of a management system, the system can obtain some information concerning the student from the teacher, and also provide the diagnostic results about the student's learning states to the teachers after instruction. In our approach, ICAI is not only an instructional tool concerned with the interaction with students, but is also an assistant environment for teachers to learn more about the students.

From the system designers' points of view, it is more convenient to implement the control program for the generation of teaching scripts by applying our dynamic analysis strategy. Only a few versions of curriculums and some assistant subject materials are needed in our system implementation phase, instead of many versions of subject material which have to cover all combinations of the personalities in the student model. For example, assume that the degree of the five characteristics in the student model is divided into three levels. In the worst case, the system might have to store 3^5 versions of formal subject contents with different presentation degrees by a static analysis method. While in our approach, the system only needs to maintain three versions of formal subject materials and some assistant subject materials to generate a variety of teaching scripts dynamically. Therefore, the development costs, taken in knowledge acquisition and implementation phases, could be saved with our approach.

References

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1. A. Takeuchi and S. Otsuki, "A study of student models and learner-machine interation", *Artificial Intelligence Tools in Education*, pp. 87-105, 1988.
2. A. Lesgold, "Toward a Theory of Curriculum for Use in Designing Intelligent Instructional Systems", *Learning Issues for Intelligent Tutoring Systems*, 1988.
3. A. Gisolfi, A. Dattolo and W. Balzano, "A fuzzy approach to student modeling", *Computers Educ.*, Vol. 19, No. 4, pp. 329-334, 1992.
4. R. R. Burton, "Diagnosing bugs in a simple procedural skill", In D. Sleeman and J. S. Brown (Eds.), *Intelligent Tutoring Systems*, pp. 157-182, 1982.
5. P. D. Mitchell and P. D. Grogono, "Modeling techniques for tutoring system', *Computer Education*, Vo. 20, No. 1, pp. 55-61, 1993.
6. J. Giarratano and G. Riley, Expert Systems: principles and programming, *PWS-KENT Publishing*, 1989.
7. G. J. Hwang, F. R. Chen and S. S. Tseng, "Development of a knowledge acquisition system for computer-assisted instruction", *International Conference on Computers in Education*, 1993.
8. H. W. Hsaio, S. S. Tseng and G. J. Hwang, "An evaluation model for the development of intelligent CAI systems", *International Conference on Computers in Education*, 1993.
9. J. Self, "Student models: What use are they?", *Artificial Intelligence Tools in Education*, pp. 73-85, 1988.
10. K. Vanlehn, "Student modeling", Martha C. Polson and J. Jeffrey Richardson (Eds.), *Foundations of Intelligent Tutoring Systems*, pp. 55-78, 1988.
11. O. C. Park, R. S. Perez and R. J. Seidel, "Intelligent CAI: old wine in new bottle, or a new vintage?", In Greg P. Kearsley (Ed.), *Artificial Intelligence and Instruction: application and methods*, pp. 11-45, 1987.
12. P. Fung, "Do-it-yourself student modelling", *Computers Educ.*, Vol. 20, No. 1, pp. 81-87, 1993.
13. P. F. Merrill, M. N. Tolman, L. Christensne, K. Hammons, B. R. Vincent and P. L. Reynolds, Computers in Education, *Prentice-Hall*, 1986.
14. P. Harmon, "Intelligent job aids: how AI will change training in the next five years.", In Greg P. Kearsley (Ed.), *Artificial Intelligence and Instruction: application and methods*, pp. 165-192, 1987.
15. S. M. Alessi and S. R. Trollip, Computer-Based Instruction: Methods and Development, *Prentice-Hall*, 1985.

智慧型化學課程電腦輔助教學系統之研製

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摘　要

電腦在教育上的應用已隨著微電腦的普及化而快速發展，並且在人類學習上扮演逐漸重要的角色。從1970年開始，人工智慧的技術被應用到電腦輔助教學（CAI）的設計上，形成所謂的「智慧型電腦輔助教學」（Intelligent CAI或ICAI），以克服傳統電腦輔助教學的限制，使系統能夠用較智慧、較具彈性的方式來教導學生，以期達到更佳的學習效果。

本論文的目的是要發展一個高中化學電腦輔助教學系統，讓系統以較爲聰明的方式輔助教學活動。因此，我們不只注重使用者界面和教材的設計，還特別分析學生的行爲及個人特質，系統能夠針對互異的學生提供不同的教學腳本與教學程序，達到因材施教的目的。除此之外，我們並研發出一套管理系統，以協助教師瞭解學生的學習狀況及個人特質。

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Elementary and Middle School Students' Perception of Science, Scientists, and Their Work

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ABSTRACT

The purpose of this study was to examine elementary and middle school students' perceptions of science, scientists, and their work. The interview-about-instance (IAI) procedure was utilized to interview elementary school grades 1, 3, 5 and middle school grade 2 students, 297 in total, with modified Boylan's 30 pairs of illustrations concerned with the physical appearance, gender, work tasks, workplace, and employment of scientists. Results showed that different grade level students made different initial responses in relation to most of the illustrations (22 out of 30 items). Moreover, the comments of their initial responses revealed an increase in sophistication across the four grade levels. Lower grade level boys and girls made similar initial responses to most of the illustrations, and higher grade level students revealed an increased difference between boys' and girls' ideas on scientist appearance items. It seems that greater differences among different schools existed in grade 1 students than with any other grade level students.

Key words: students' perception of science and scientists, gender difference, grade level difference, school difference

I. Introduction

Many studies have assumed that students' attitudes toward science are greatly influenced by their perceptions of science and scientists (Boylan, Hill, Wallace, Wheeler, 1992; Kahle, 1988). Boylan (1992) also suggested that attitudes are influenced by their images of science which are largely determined by the way science is portrayed in the media. Hassard (1990) found that media portrays scientists as brilliant, cold-blooded, bald, with frizzy wild hair, a crazed look on the face, wearing glasses and a white lab coat, seeking to cure humanity's ills but instead unleashing new horrors on the human race, also inspiring both respect and terror at the same time. He concluded that this perception is the root of cause students science anxiety among students. Sjoberg (1993) noted that pupils gradually develop ideas about what science is really all about and what scientists are like as persons. He further addressed that the image of science is probably more stable in children's minds than the facts and laws which they learn at school. Therefore, probing students perceptions about science and scientists become an important and revealing work.

According to Gottfredson (1981), occupational images become more realistic as students progress through secondary school. These images usually involve similarities and differences in a number of dimensions including gender, prestige, work conditions and types of task. The personal career choices of girls in the areas of science and technology become more restrictive between fifth and seventh grades (Erb, 1981, 1983; Utmost, 1980). The junior high years are the most critical period in the determination of gender-role interests and differences in achievement between boys and girls in science and mathematics (Deboer, 1984; Fox, 1976; Hardin & Dede, 1973). Fox (1976) further mentioned that social factors also appears feasible for the explanation of why girls start to "taper off" in their interest in science. Moreover, according to Kelly (1987) and other authors, whose papers she collected in *Science for Girls*, girls tend to see science in the following terms: competitive, impersonal, convergent, abstract, restrictive, male, unimaginative, mechanistic, certain and rule bound. Keeves (1975) identified three educational environments (home, school, and peer group) that interact to influence achievement and attitudes toward schooling. In addition, Talton and Simpson (1986) found that self, family, and classroom were significant predictors of attitudes toward science.

On account of the above literature reviewing, three major factors were taken into consideration in the examining of students' image of science and scientists in this study, which were grade level, student gender, and school environment. Three research questions were examined for this 30 series of illustrations concerned with the physical appearance, gender, work task and employment of scientists. The first research question examined the different grade level students' perceptions of science, scientists, and their work. The second research question examined boys' and girls' perceptions about science, scientists, and their work. The third research question examined the different schools students' perceptions of science, scientists, and their work.

II. Methods

1. Subjects

A total of 297 students (153 male, 144 female) were involved in this study; these included 76, 81, 80, and 60 students from elementary school grades 1, 3, 5, and middle school grade 2 students (grade 8), respectively. The numbers of male and female student subjects distributed in each grade are shown in Table 1. All those students were randomly selected from three elementary schools and three middle schools in Taiwan.

Table 1. The Numbers of Male and Female Subjects Across Four Grade Levels

	Male	Female	Total
Grade 1	39	37	76
Grade 3	42	39	81
Grade 5	42	38	80
Grade 8	30	30	60
Total	153	144	297

2. Instrument

The modified Boylan's 30 pairs of illustrations of science and scientists (Boylan, et. al., 1992) were used as part of the interview-about-instances (IAI) procedure (Osborne & Gilbert, 1979) to probe students' perceptions about what scientists look like, what they do, and where they work. There are 30 pairs of illustrations consisted of the areas of appearance (illustrations 1-10), the workplace (illustrations 11-14), the work task (illustrations 15-19), and the employment/gender of scientists (illustrations 20-30) (Appendix 1).

3. Procedure

This study employed the interview-about-instances (IAI) procedure (Osborn & Gilbert, 1979) to interview students with the modified Boylan's 30 pairs of illustrations in order to probe students' ideas about who is a scientist, where they work and what they do in this study. The interviewer's questions were developed according to the illustrations by Boylan, et. al. (1992). For instance, questions were asked in appearance illustrations: "Is one of the persons more likely to be a scientist than the other or could they both be scientists or could neither be a scientist-why do you think so?" Each student was interviewed with the complete set of 30 pairs of illustrations for 30 to 45 minutes. The interviews were held within one month during June 1993.

4. Data Analysis

Students' responses to each pair of illustrations were treated in two parts. First, students initial responses to each pair of illustrations were presented with four categories of choice: neither(N); left(L); right(R); or both(B) illustrations. These categorical data were statistically analyzed via percentage and Chi-square using $p<0.05$ as the critical value. The Chi-square and percentage was conducted with SAS statistical package. Second, the reasons supplied by the students were analyzed via a qualitative approach which served to support and expand the results obtained from students' initial responses to each pair of illustrations.

III. Results and Discussions

1. Grade Level Difference

Results showed that there were statistically significant differences among four grade level students' initial responses in relation to most of the illustrations (22 out of 30 items), which included six of the ten appearance items, all of four workplace items, four of the five work task items, and eight of the eleven employment items (Table 2). Interestingly, Boylan et. al. (1992) found only five items reached significant difference level, which is quite different from our results. However, their results (Boylan, et. al., 1992) on students' comments of their initial responses revealed an increase in sophistication and complexity according to grade level, which supports our findings.

A. Appearance of Scientist

The percentage of students' choices, most of the four grade level students favored scientists as wearing glasses (grades 1, 3, 5, 8: 49%, 51%, 60%, 47%) and lab coat (grades 1, 3, 5, 8: 61%, 71%, 75%, 52%), which is consistent with Boylan, et. al (1992) results.

Table 2. The Number of Students (N=297) at Each Four Grade Levels Selecting the Right (R), Left (L), Neither (N), Both (B) Illustrations Together with the Chi-Squared Statistic and Probability

Illustration	Grade 1				Grade 3				Grade 5				Grade 8				χ^2	p
	R	L	N	B	R	L	N	B	R	L	N	B	R	L	N	B		
1	9	32	7	24	4	45	6	25	5	44	4	27	4	8	6	41	37.878***	0.000
2	21	13	27	11	19	12	39	9	22	7	39	11	14	7	27	12	6.643	0.674
3	23	31	4	17	35	19	2	22	34	8	7	31	26	5	3	25	34.131***	0.000
4	10	37	10	18	7	41	9	23	1	48	3	28	1	28	8	23	20.493*	0.015
5	4	46	14	11	3	57	8	11	6	60	6	8	5	31	7	16	15.982	0.067
6	57	1	6	6	59	9	9	3	49	20	3	8	12	21	3	24	89.210***	0.000
7	22	29	15	9	16	31	24	8	20	16	30	14	21	6	21	12	25.941**	0.002
8	5	18	41	10	1	24	45	8	4	21	45	9	5	13	28	14	10.809	0.289
9	12	32	14	17	24	29	14	10	24	16	8	32	28	4	5	23	48.259***	0.000
10	12	21	22	20	12	25	26	15	7	38	24	11	7	19	19	14	10.706	0.296
11	28	31	4	13	38	24	0	19	32	9	1	38	26	5	0	28	48.031***	0.000
12	40	14	0	22	30	21	1	29	25	18	0	37	12	18	0	30	20.371*	0.016
13	10	46	3	17	20	37	3	21	15	29	0	36	12	15	1	32	30.301***	0.000
14	21	43	5	7	12	45	6	17	11	45	1	23	3	16	0	41	70.051***	0.000
15	9	31	4	32	6	25	2	48	6	30	2	42	4	17	2	37	7.786	0.556
16	22	27	9	18	16	34	20	11	14	26	14	26	11	6	11	32	38.441***	0.000
17	32	13	3	28	14	26	4	36	17	20	8	34	16	12	4	28	18.008*	0.035
18	38	6	2	30	32	7	3	39	26	10	2	42	6	9	0	45	29.227**	0.001
19	18	31	12	15	16	27	21	17	12	40	9	19	2	27	6	25	27.543**	0.001
20	6	14	4	52	3	7	5	66	1	9	2	68	5	3	0	52	17.437*	0.042
21	6	17	20	33	1	5	46	28	3	5	50	22	2	4	39	15	36.364***	0.000
22	4	13	18	41	2	12	25	42	1	8	30	39	0	7	23	30	9.590	0.385
23	4	7	39	26	1	6	55	19	0	6	54	20	2	4	39	15	9.908	0.358
24	5	2	35	34	1	3	57	18	0	3	62	15	1	1	39	19	26.012**	0.002
25	4	14	16	42	2	8	21	49	0	1	33	46	0	0	39	21	53.453***	0.000
26	5	12	24	35	2	5	21	52	1	3	24	51	2	0	14	44	23.389**	0.005
27	0	8	35	33	1	5	43	32	1	5	28	45	0	2	10	47	29.112**	0.001
28	5	11	11	489	2	2	28	47	3	3	40	34	0	1	34	24	44.009***	0.000
29	17	15	32	12	11	16	42	11	10	15	44	11	2	18	31	9	13.174	0.155
30	5	18	51	2	0	7	72	2	1	12	66	1	1	6	50	3	19.717*	0.020

NOTE. *p<.05 **p<.01 ***p<.001

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There were statistically significant differences on six of the ten scientists' appearance items (illustrations 1, 3, 4, 6, 7, 9) among four different grade levels students responses (Table 2). Two major differences existed among these four grade levels. First, higher grade level students received more public stereotype influence on scientists' looks than lower grade level students. For instance, more grades 3, 5, and 8 students than grade 1 considered that bearded males (45%, 43%, 44%, 31%) were more likely to be scientists than clean shaven males (24%, 10%, 8%, 41%). Grades 1, 3, and 5 preferred a full head of hair, and grade 8 preferred bald males. This supports Chambers (1983) findings, the number of scientists indicators drawn by students increased with grades.

Second, lower grade level students were more conservative as to the gender and race of scientists than higher grade students. Many grade 1 students said "most scientists are men and not women, because men are smart than women". Several grade 8 students mentioned, "Both men and women could be scientists if they are interested in science or they have observation ability". More grade 8 considered both male and female Caucasians to be scientists than grades 1, 3, 5 (41%, 24%, 25%, 27%). More grades 5 and 8 (18%, 20%) than grades 1 and 3 (12%, 10%) considered both pan-Asian males and Indian males could be scientists. Many higher grade level students felt "not only Chinese people can be scientists. Other nations' people, for instance, Americans, Indians, and Arabs also could possibly be scientists".

B. Workplace

Table 2 indicated that all the four workplace items (illustration 11, 12, 13, 14) reached statistically significant difference level, at the 5% level. In general, as students progress to the upper grade level, they perceive scientists' workplace more realistically than in the lower grade level, which is consistent with the Gottfredson (1981) study. For instance, grade 8 students considered library, traditional lab, modern chemistry lab, and outdoor field plots all possible for scientists to work at; grade 5 students did not think of outdoor field plots as workplaces for scientists. The majority of grades 1 and 3 only considered laboratory as scientists' workplace. Many grade 8 students responded, "Scientists need to look for information at the library and invent new products in the laboratory." Several grade 3 students mentioned, "Library is a place for people to read and not for scientists to invent new products in".

C. Work Tasks

Most of the students considered that discussing and drawing what is seen through a microscope was a more "scientific" practice, which supports Boylan, et. al (1992) findings.

Table 2 indicated that four of five work task items (illustration 16, 17, 18, 19) reached a significant difference level among the four different grade level students. Overall, the perception of grade 1 students on scientists' work tasks is more limited than higher grade students. For instance, grade 1 students thought reading an instrument and entering data into a computer are more likely than reading a book or writing a report to be scientists' work tasks. A typical comment made by grade 1 students was "Scientists do not give animals shots. It is a veterinarian's job". On the other hand, several grade 5, and 8 students reacted: "Animals usually were used to do vaccine test or different kinds of experiment by scientists."

D. Employment

According to the responses of four grade level students on ten employment items, eight out of ten employment items (illustration 20, 21, 24, 25, 26, 27, 28, 30) reached a significant difference level (Table 2). Several kinds of employment were not considered by the majority of students as scientific jobs, which were powerhouse technician, doctor, nuclear reactor operator, surveyor, designer, builder, and construction worker. Analytical chemist and TV technician were considered as legitimate scientific professions by most students. Unlike Boylan, et. al. (1992), in this study most students perceived illustration 22 as TV developer and researcher, not TV technician.

The majority of lower grade level students perceived pharmacist (grade 1), science teacher (grades 1, 3), and data entry operator (grades 1, 3, 5) as a scientific profession, and most of the higher grade level students (grades 5, 8) considered agronomist as a scientific job. In general, as students progress to a higher grade level, their ideas of legitimate scientific professions get clearer. It supports Gottfredson's (1981) study, that occupational images usually become more realistic as students progress through secondary school.

2. Gender Difference

The results of the second research question indicated that there were no statistically significant differences between boys and girls responses on all of the 30 items within grade 1. In grades 3 and 5, only two items (illustration 3, 20; illustration 15,18) were significantly different between boys and girls (Table 3, 4). Within grade 8, four of the ten appearance items (illustration 5, 7, 8, 10) and two of the five work task items (illustration 16, 17) were significantly different between boys and girls (Table 5). The results of this study indicated that lower grade level boys and girls made similar initial responses in relation to most of the illustrations; and as students move into higher grade level an increased difference between boys and girls initial responses to the illustrations was revealed, especially on the appearance items. Moreover, many grade 8 female students felt that both male and female students could possibly become scientists; on the other hand, most of them did not want to pursue scientific careers in the future. They did not believe themselves smart enough, or some of them did not want to be considered as strange persons. This result is supported by the Mead & Metraux (1957) study, in which students described scientists in general as people who were responsible for progress, who improved the quality of life and who improved the health of the population. But when the question concerned science as a career choice for themselves or their spouses, the responses were overwhelmingly negative.

3. School Difference

Table 3. The Number of Male and Female Students (M=42, F=39) at Third Grade Level Selecting the Right (R), Left (L), Neither (N), Both (B) Illustrations Together with the Chi-Squared Statistic and Probability

Illustration	Male				Female				χ^2	p
	R	L	N	B	R	L	N	B		
1	2	23	3	13	2	22	3	12	0.012	1.000
2	8	4	24	5	11	8	15	4	3.887	0.274
3	17	6	0	17	18	13	2	5	11.109*	0.011
4	4	19	5	13	3	22	4	10	0.815	0.846
5	0	30	3	8	3	27	5	3	5.825	0.120
6	31	3	6	2	28	6	3	1	2.292	0.514
7	8	14	14	6	8	17	10	2	2.651	0.449
8	0	14	4	8	10	15	10	2	6.766	0.080
9	14	14	4	8	10	15	10	2	6.766	0.080
10	8	10	15	8	4	15	11	7	2.818	0.421
11	20	12	0	10	18	12	0	9	0.047	0.977
12	15	10	0	17	15	11	1	12	1.801	0.615
13	11	17	2	12	9	20	1	9	1.096	0.778
14	4	22	3	12	8	23	3	5	4.191	0.242
15	3	11	2	26	3	14	0	22	2.586	0.460
16	8	16	11	7	8	18	9	4	1.026	0.795
17	10	11	2	19	4	15	2	17	3.106	0.376
18	15	4	2	21	17	3	1	18	0.722	0.868
19	7	13	13	9	9	14	8	8	1.427	0.699
20	1	0	4	37	2	7	1	29	10.006*	0.019
21	0	2	23	17	1	3	23	11	2.291	0.514
22	2	3	14	23	0	9	11	19	5.638	0.131
23	0	3	28	11	1	3	27	8	1.383	0.710
24	1	1	30	9	0	2	27	9	1.379	0.710
25	0	4	9	29	2	4	12	20	3.891	0.273
26	1	1	11	29	1	4	10	23	2.346	0.504
27	0	2	22	18	1	3	21	14	1.614	0.656
28	2	0	11	29	0	2	17	18	7.574	0.056
29	6	6	23	7	5	10	19	4	2.095	0.553
30	0	5	35	2	0	2	37	0	3.235	0.198

NOTE. *p<.05

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Table 4. The Number of Male and Female Students (M=42, F=38) at Fifth Grade Level Selecting the Right (R), Left (L), Neither (N), Both (B) Illustrations Together with the Chi-Squared Statistic and Probability

Illustration	Male				Female				χ^2	p
	R	L	N	B	R	L	N	B		
1	1	25	1	15	4	19	3	12	3.761	0.288
2	12	4	19	6	10	3	20	5	0.328	0.955
3	20	2	3	17	14	6	4	14	3.300	0.348
4	0	27	2	13	1	21	1	15	2.031	0.566
5	4	33	2	3	2	27	4	5	2.239	0.524
6	23	12	3	4	26	8	0	4	3.793	0.285
7	13	6	14	9	7	10	16	5	3.886	0.274
8	4	10	22	5	0	11	23	4	4.073	0.254
9	9	9	6	18	15	7	2	14	4.060	0.255
10	3	19	15	5	4	19	9	6	1.538	0.674
11	20	3	1	18	12	6	0	20	3.915	0.271
12	14	9	0	19	11	9	0	18	0.187	0.911
13	5	14	0	23	10	15	0	13	4.290	0.117
14	3	26	1	12	8	19	0	11	4.216	0.239
15	2	21	2	17	4	9	0	25	8.813*	0.032
16	9	11	9	13	5	15	5	13	2.708	0.439
17	13	10	3	15	4	10	5	19	5.629	0.131
18	20	4	2	16	6	6	0	26	12.105**	0.007
19	8	19	5	10	4	21	4	9	1.401	0.405
20	1	2	2	37	0	7	0	31	6.122	0.106
21	1	3	30	8	2	2	20	14	3.980	0.264
22	0	3	16	22	1	5	14	17	2.075	0.557
23	0	3	31	8	0	3	23	12	1.790	0.409
24	0	2	34	6	0	1	28	9	1.317	0.518
25	0	1	4	27	0	0	19	19	2.956	0.228
26	1	1	14	26	0	2	10	25	1.710	0.635
27	1	2	14	24	0	3	14	21	1.288	0.732
28	2	1	23	16	1	2	17	18	1.488	0.685
29	3	6	27	6	7	9	17	5	4.375	0.224
30	1	4	36	1	0	8	30	0	3.688	0.297

NOTE. *p<.05 **p<.01

The results of the third research question showed that different schools students within each grade level made similar initial responses to most of the illustrations; but there were five (illustration 12, 13, 14, 16, 17), three (illustration 11, 22, 29), two (illustration 1, 25), and three (illustration 6, 13, 28) items reacted by grades 1, 3, 5, and 8, respectively, reached significant difference level among different schools. It demonstrated that greater difference among different schools existed in grade 1 students than with any other grade students. On the other hand, there is a greater degree of difference of comments and reactions about science and scientists provided by those students whose schools located at suburban areas and urban areas, particularly in the lower grade level. Keeves (1975) identified three educational environments (home, school, and peer group) that interact to influence achievement and attitudes toward schooling. Moreover, though there are many studies which support the idea that school environment has a strong relationship with student attitudes toward science (Talton & Simpson, 1986; Haladyna, Olsen, & Shaughnessy, 1982), there is no specific study which mentions whether younger students will be more possible to be influenced by school environment than older students. Further study is highly recommended.

IV. Conclusions and Implications

Our results showed that different grade students' perceptions of science and scientists were different to most of the illustrations (22 out of 30 items) among four different grade levels. Higher grade level students received greater influence

Table 5. The Number of Male and Female Students (M=30, F=30) at Eighth Grade Level Selecting the Right (R), Left (L), Neither (N), Both (B) Illustrations Together with the Chi-Squared Statistic and Probability

Illustration	Male				Female				χ^2	p
	R	L	N	B	R	L	N	B		
1	1	3	3	22	3	5	3	19	1.703	0.636
2	6	2	13	9	8	5	14	3	4.608	0.203
3	12	4	0	13	14	1	3	12	4.978	0.173
4	0	15	2	13	1	13	6	10	3.534	0.316
5	0	11	3	15	5	20	4	1	19.995***	0.000
6	8	8	2	12	4	13	1	12	2.857	0.414
7	11	3	6	10	10	3	15	2	9.238*	0.026
8	3	7	9	11	2	6	19	3	8.420*	0.026
9	13	2	1	14	15	2	4	9	3.030	0.387
10	1	9	7	12	6	10	12	2	12.069**	0.007
11	13	2	0	14	13	3	0	14	0.183	0.913
12	6	9	0	15	6	9	0	15	0.000	1.000
13	4	8	0	18	8	7	1	14	2.900	0.407
14	1	7	0	22	2	9	0	19	0.803	0.669
15	3	9	1	17	1	8	1	20	1.302	0.729
16	4	0	6	20	7	6	5	12	8.909*	0.031
17	11	3	4	12	5	9	0	16	9.821*	0.020
18	3	2	0	25	3	7	0	20	3.333	0.189
19	1	12	2	15	1	15	4	10	2.000	0.572
20	1	1	0	28	4	2	0	24	2.441	0.295
21	0	2	20	8	2	2	19	7	2.092	0.553
22	0	2	12	16	0	5	11	14	1.463	0.481
23	0	2	20	8	2	2	19	7	2.092	0.553
24	0	0	17	13	1	1	22	6	5.220	0.156
25	0	0	19	11	0	0	20	10	0.073	0.787
26	0	0	9	21	2	0	5	23	3.234	0.199
27	0	1	2	26	0	1	8	21	4.116	0.128
28	0	0	17	12	0	1	17	12	0.983	0.612
29	2	6	17	5	0	12	14	4	4.401	0.221
30	0	4	24	2	1	2	26	1	2.080	0.556

NOTE. *p<.05

from the mass media and society's recognition of scientists' appearance than lower grade level students. As students progress into higher grades, their perceptions about scientific work tasks, work places, and employment get more realistic and clearer. It also showed the differences between male and female students' perceptions about science and scientists also increase as students move into higher grade levels, especially the items on scientists' appearance. In addition, with grade 1 students greater differences existed among different schools than with other grade level students. Also, students whose school located at suburban areas revealed some degree of difference on their reactions about science and scientists than those whose school located at urban areas, especially among lower grade students.

Previous research suggests that teaching in a particular way can affect students' images of scientists (Kahle, 1993). Kahle (1993) also found that there is a growing evidence showing teacher behavior and instructional strategies affect students' skills, interest and retention rates in science. In addition, Lustig (1989) also mentioned that the school curriculum may assist in this process and teachers in both elementary and high schools need to consider their role carefully. Therefore, finding ways to infuse school science with an accurate and neutral image of science and scientists for a wide variety of students is important and valuable.

Several recommendations are provided in the followings. As science educators, we might encourage students to extend their ideas about science and scientists through the sharing and clarification of students' existing conceptions (Bentley and Watts, 1989). Both primary and secondary teachers need to organize classroom activities so that girls have extra time and opportunities to do science, and so that they are expected to perform to the same level as boys (Kahle, 1993). In addition, we highly recommend to provide suburban schools with more resources, and give teachers more supports on their professional works and time to refresh themselves. Hopefully, our students would have more and equal opportunities to experience science and establish neutral image about science, and with their age increase they would be able to appreciate and give science and scientists works respects.

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Bibliography

Bentley, D., & Watts, M. (1989). Learning and teaching in school science: Practical alternatives. Philadelphia: Open University.

Boylan, C.R., & Hill, D. M., & Wallace, A. R., & Wheeler, A. E. (1992). Beyond Stereotypes. *Science Education*, *76*(5), 465-476.

Kelly, A. (Ed.) (1987). Science for Girls? Milton Keynes, Open University Press.

Deboer, G.E. (1984). A study of gender-effects in the science and mathematics taking behavior of a group of students who graduated from college in the late 1970s. *Journal of Research in Science Teaching*, *21*(1), 95-103.

Erb, T. O. (1981). Attitudes of early adolescents toward science, women in science, and science careers. In Erb, T. O. (Ed.), *Middle school research: Selected studies 1981* (*pp. 108-118*). Fair born. OH: National Middle School Association.

Erb, T. O. (1983). Career preferences of early adolescents: Age and sex differences. *Journal of Early Adolescence*, *3*, 349-359.

Fox, L. H. (1976). The effects of sex role socialization on mathematics participation and achievement. Washington, DC: Career Awareness Division, National Institute of Education, U.S. Department of Health, Education and Welfare.

Gottfredson, L. S. (1981). Circumspection and compromise: A developmental theory of occupational aspirations. *Journal of Counseling Psychology*, *28*, 545-579.

Haladyna, T., Olsen, R., & Shaughnessy, J. (1982). Relations of student, teacher, and learning environment variables to attitudes toward science. *Science Education*, *66*(5), 671-687.

Hardin, J., & Dede, C. J. 91973). Discrimination against women in science education. *Science Teacher*, *40*(9), 239-241.

Kahle, J. B. (1993). Images of scientists: Gender issues in science classroom. In Fraser, J. B. (ed.) , *Research implications for science and mathematics teachers, vol. 1.* Curtin University of Technology, Perth, Western Australia.

Kahle, J. B. (1988). Gender and science education II. In Fensham, P. (ed.), *Development and dilemmas in science education*. Philadelphia: The Falmer Press.

Kahle, J. B. (1987). SCORES: A project for change? *International Journal of Science Education*, *9*, 325-333.

Keeves, J. P. (1975). The home, the school, and achievement in mathematics and science. *Science Education*, *59*(4), 439-460.

Kelly, A. (Ed.) (1987). Science for Girls? Milton, Keynes, Open University Press.

Lustig, A. (1989). Non-sexist education and paradigms for change. *Curriculum Perspectives*, *9*(4), 17-27.

Mead, M., & Metraus, R. (1957). Image of the scientist among high-school students: A pilot study. *Science*, *126*, 384-390.

Osborne, R. J., & Gilbert, J. K. (1979). *Investigating student understanding of basic physics concepts using an interview-about-instance technique.* Paper presented at the Australian Science Education Research Association Conference, Perth.

Sjoberg, S. (1993). Gender equality in science classrooms. In Fraser, J. B. (ed.), *Research implications for science and mathematics teachers, vol. 1.* Curtin University of Technology, Perth, Western Australia.

Talton, E. L. and Simpson, R. D. (1986). Relationship of attitude toward classroom environment with attitude toward achievement in science among tenth grade biology students. *Journal of Research in Science Teaching*, *24*(6), 507-525.

Utmost, M. E. (1980). Occupational sex-role liberality of third-, fifth-, and seventh-grade females. *Sex Roles*, *6*(4), 611-617.

Appendix 1. Descriptions of 30 pairs illustrations

(1). Appearance (illustrations 1-10)

	Left	Right
1.	Young Caucasian male in lab coat	Young Caucasian female in lab coat
2.	Asian male in laboratory coat	Young Asian female in laboratory coat
3.	Young male clean shaven	Young male with beard
4.	Young male with glasses	Young male identical without glasses
5.	Young male in laboratory coat	Young male in casual clothes
6.	Young male, untidy	Young male, tidy
7.	Pan-Asian male	Indian male
8.	Male, cheerful	Male, serious
9.	Male-full head of hair	Male, bald
10.	Female simply dressed with lab coat	Stylish female with lab coat
(2).	Wotk place (illustrations 11-14)	
11.	Library	Traditional school laboratory
12.	Traditional school laboratory	Modern chemistry laboratory
13.	Modern chemistry laboratory	Traditional school laboratory
14.	Traditional school labortory	Outdoor field plots
(3).	Work tasks (illustrations 15-19)	
15.	Drawing what was seen through microscope	Drawing a graph
16.	Using a mortar and pestle	Giving an injection to a laboratory animal
17.	Reading a book	Reading an instrument
18.	Writing a report	Entering data into a computer
19.	Discussing with another scientist	Listening to a cassette with headphones
(4).	Employment (illustrations 20-30)	
20.	Male analytical chemist	Female analytical chemist
21.	Male pharmacist	Female pharmacist
22.	Male TV technician	Female TV technician
23.	Male powerhouse technician	Female powerhouse technician
24.	Male doctor	Female doctor
25.	Male data entry operator	Female data entry operator
26.	Male nuclear reactor operator	Female nuclear reactor operator
27.	Male agronomist	Female agronomist
28.	Male science teacher	Female science teacher
29.	Male surveyor	Male designer
30.	Male building foreman	Male bricklayer

Illustrations were developed by Boylan, et. al. in 1992.

中小學學生的科學與科學家印象之比較研究

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摘　要

本研究的主要目的是探討國中和國小不同年級的學生對於科學與科學家印象和看法之異同，同時希望了解不同性別的學生和不同學校的學生是否也有差異性存在。本研究採用Osborne和Gilbert（1979）所發展之IAI（interview-about-instances）法給予國小一、三、五和國中二年級共297位學生30組Boylan設計之科學與科學家圖片測驗，並同時進行一對一訪談以期了解學生們選擇圖片的看法與個中原因。

結果發現不同年級的學生對30組科學與科學家圖片的選擇有22組達顯著性差異。而學生們對科學與科學家印象所持之看法原因也隨著年齡增加，受到媒體和社會的影響隨之增大，其複雜性也相對增高。此外，發現低年級不論男女學生對於大部分的圖片之選擇和看法很相似且大多認爲男性較可能成爲科學家，而高年級男女學生對於科學家外表之印象則隨年齡增加其差異性也逐漸增大。不同學校的低年級學生間之科學與科學家印象看法的差異性比高年級來的大。

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The Logical Thinking Ability and the Integrated Science Process Skills of Junior High School Students in Taiwan†

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ABSTRACT

The logical thinking abilily and the integrated science process skills of seventh through ninth grade students (N=1892) in Taiwan were studied by four kinds of evaluation methods–Group Assessment of Logical Thinking (GALT), Test of Integrated Science Process Skills II (TIPS II), Science Attitude Scale (SAS), and Science Activities (out of school) Questionnaire (SAQ). Differences in sex, grade, and cognitive developmental levels on logical thinking and integrated science process skills were tested by t-test or analysis of variance (ANOVA) respectively. The correlation among logical thinking, science process skills, attitudes towards science, and science activities of junior high school students were also studied.

The following were the results of this study: (1) The mean and SD scores for all students on GALT and TIPS II are 4.28, 17.50, and 0.26, 6.43, respectively. The number of students in the formal operation stage is increased with higher grades. (2) Besides sex, differences in grades and cognitive developmental levels on logical thinking and integrated science process skills were all significant. (3) Differences in sex on integrated science process skills were not significant, but on logical thinking were significant. (4) Logical thinking and science process skills were positively correlated with attitudes to science, science activities and the socioeconomic status of parents.

Key words: logical thinking, integrated science process skills, attitude to science, science activities, junior high school students.

I. Introduction

The development of cognitive ability is one of the major objectives of science education (Nakayama, 1988). It is of great value in science education to study the student's formal reasoning and thinking abilities (Cohen, 1980). Formal reasoning ability is important for the student in studying science, understanding of scientific content and scientific processes (Lawson *et al.*, 1978). Raven (1974) indicated that the acquisition and understanding of scientific concepts are related to the operation of logical thinking; that is, scientific concepts matched with the level of cognitive development of students will be of benefit to their study. Preece (1978) considered it of great importance for teachers to match the subject materials with students' level of cognitive development. At the same time, teachers have to recognize what limitations students have in cognition (Allen, 1978). If the activity they participate in is beyond their level of cognitive development, this will not only limit the value but might also cause harm to students.

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If a teacher wants to obtain excellent results in science instruction, the teaching materials and methods have to match the level of students' cognitive development. First of all, the teacher has to understand the level of cognitive development of the student. Then he can form a suitable strategy in order to accomplish effective instruction.

For a long time, logical thinking has been studied by Piaget and other cognitive psychologists. The cognitive development theory of Piaget classified cognitive developmental levels into four stages: (1) the sensorimotor stage, (2) the preoperational stage, (3) the concrete operational stage and (4) the formal operational stage. Inhelder and Piaget (1958) identified the intellectual transition from the concrete operational stage to the formal operational stage by several clinical interview tasks. These tasks can evaluate "controlling variables", "explaining physical phenomena ", "combination", "proportional reasoning", "explaining compensation" and "separating variables". The clinical interview method suffered from a time-consuming and non-standardized procedure due to poorly-trained interviewers, so that some investigators concentrated on developing logical thinking classroom tests (paper-pencil tests) with better reliability and validity. In the paper-pencil test of Lawson (1978), besides picking the correct answer, students should write down their reasons. The Test of Logical Thinking (TOLT) developed by Tobin & Capie (1981) is an all multiple choice-type paper pencil test. Cohen (1980) pointed out that most items in previous paper-and-pencil tests made use of only simple literal descriptions to explain the problems or situations. Indeed, Cohen suggested more diagrams or tables should be used to help students understand the situations or meanings in the tests. From this point of view, Roadrangka *et al.* (1983) developed "the group assessment of logical thinking (GALT)". This instrument includes six modes of logical thinking: conservation, proportions, control variables, probability, correlations and combination. Most of these items are selected from Lawson's "Classroom Test of Formal Operation"; others are from the tests developed by Burney (1974), Ankney & Joyce (1974), and Longeot (1965). GALT was administered to students from grade seven to grade twelve by Bitner (1987) to test their logical thinking ability, and then he tested the logical thinking ability of students from grade six to grade twelve with the same method, in order to investigate the formal thinking mode as a predictor of reflexive thinking ability and academic achievement (Bitner, 1988a, 1988b). The Japan-US cooperative research groups directed by Mattheis (Mattheis *et al.*, 1985, 1986) and Takemura (Takemura *et al.*, 1985, 1987) study logical thinking ability and its related factors by administering GALT to junior high school students from grade seven to grade nine in 1984-1985, in Japan and the U.S. respectively. Manzano (1986) tested the logical thinking ability of junior high school students in the Philippines by GALT, and discussed the relationships of logical thinking ability and science educational factors between Philippine and Japanese students.

Acquisition of science process skills is one of the major objectives of science education (Padilla *et al.*, 1983; Shymansky *et al.*, 1983). By learning science process skills, students can not only collect and process data, but they are also induced to appreciate science and discuss the nature of science, which will help them face the changing society of the future.

Logical thinking, the basic ability of learning advanced scientific concepts (Bitner, 1988) is an important factor affecting science process skills (Padilla, *et al.*, 1983; Tobin & Capie, 1982). In Science-A Process Approach (SAPA) Lesson, science process skills were sorted into basic science process skills and integrated science process skills. Integrated science process skills include: defining operationally, formulating hypotheses, interpreting data, controlling variables and experimenting. Although many investigators cited SAPA classification for science process skills, there are many different classification methods for specific needs (Klinkmann, 1963; NSTA, 1964; NAEP, 1969; Klopfer, 1971). Walbesser (1965), Mcleod *et al.* (1975), and Ludeman (1975) all designed science process skills tests according to the SAPA Lesson. Riley (1972) developed a test of process skills for the SCIS Lesson. Molitir and George (1976) and Tannenbaum (1968) developed tests of process skills that are suitable for elementary and middle school students respectively, without focusing on a specific lesson. Tobin & Capie (1982) developed the Test of Integrated Science Process (TISP), suitable for students from middle school to college.

Dillashaw and Okey (1980) developed the

Test of Integrated Science Process skills, (TIPS) which is suitable for junior and senior high school students. This is an instrument with good reliability and validity, measuring five integrated science process skills of students from Grade 7 to Grade 12, including identifying variables, identifying and stating hypotheses, operationally defining, designing investigations, and graphing and interpreting data. Burns *et al.* (1983) developed the Test of Integrated Science Process Skills II (TIPS II) for these five process skills. Mattheis *et al.* (1985, 1986), Takemura *et al.* (1985,1987), Manzano (1986) cited TIPS II as a tool to investigate integrated process skills of junior high school students of U.S., Japan, and the Philippines respectively. Lin (1991) cited GALT and TIPS II as the tools to investigate logical thinking and the integrated science process skills of gifted students in junior high schools in Taiwan. Lin and Jeng (1991) cited GALT and TIPS II as the tools to study science process skills and its predictors of gifted junior high school students in Taiwan. Lin (1992) cited GALT as a tool to evaluate the level of development of senior and junior students in central Taiwan on the relationships between the understanding of molecular concepts and problem solving.

Padilla *et al.* (1983) reasoned that integrated science process skills and logical thinking are very similar logically. For instance, "designing experiments" involves science process skills, "controlling variables" involves logical thinking, "interpreting experimental data" in integrated science process skills has to do with "proportional and correlational reasoning" in logical thinking. They also argued that when students learn to acquire integrated science process skills, they not only improve their skills in the integrated science process, but also strengthen their abilities in logical thinking.

Baired and Borich (1985) applied multi-trait analysis methods to examine the relationship between logical thinking and integrated science process skills. They showed that these two variables were strongly correlated and they had overlapping contents. For instance, "controlling variables", "proportional reasoning" and "combinational reasoning" in logical thinking overlapped with the contents in the integrated science process skills.

The purpose of this study was to explore the logical thinking, science process skills and their correlative factors of junior high school students in Taiwan.

II. Methods

1. Samples

Taiwan was divided into five areas: Taipei, Hsingjwu, Taichung, Jia-nang, and Kaoping. Samples were selected from 7th., 8th., and 9th., grade students of junior high schools in cities, suburbs, and rural towns and villages in these five areas by cluster sampling. There were 1892 students (sample) in total with 841 males and 1051 females; across the grades, there were 609,633 and 650 students in grades 7, 8, and 9 respectively. According to region, there were 361 students from the Taipei area, 372 students from the Hsingjwu area, 396 students from the Taichung area, 369 students from the Jia-nang area, and 394 students from the Kaoping area. Across the cities, suburbs, and countryside areas, there were 636 students from cities, 648 students from suburbs, and 608 students from countryside towns and villages.

2. Research Instruments

A. The Group Assessment of Logical Thinking (GALT)

To explore students' logical thinking, this study utilized "GALT", formerly developed by Roadrangka *et al.* (1983), and translated into Chinese by Lin (1991). There are 12 items in this instrument, which can test six modes of logical thinking: conservation, proportional reasoning, controlling variables, combinational reasoning, probabilistic reasoning, and correlational reasoning. It is suitable for middle school and college students. According to the literature, this instrument has good construction validity and criterion referenced validity (Roadrangka *et al.*, 1983). Concerning the reliability of internal consistency, see Cronbach's $\alpha=0.77$ (Mattheis *et al.*, 1985) and $\alpha=0.73$ (Takemura *et al.*, 1985) respectively.

B. The Test of Integrated Science Process Skills II (TIPS II)

"TIPS II" was used to measure students' integrated science process skills. This instrument was developed by Burns *et al.* (1983) and translated later into Chinese by Lin (1991). This instrument has 36 items, which can test 5 integrated science process skills, including identifying variables, operationally defining, identifying testable hypotheses, data and graph interpretation, and experimental design. It is suitable for middle school and college students. In addition to the good content validity of this instrument (Burns *et al.*, 1983), good reliability of internal consistency was also found in several studies: Burns *et al.* (1983), α=0.86; Nakayama (1988), α=0.86 ; Mattheis *et al.*, (1985), α=0.82 and Takemura *et al.* (1985), α=0.86.

C. The Science Attitude Scale (SAS)

Science attitudes in this study were evaluated with "SAS", which was developed by Mattheis *et al.* (1985) and translated by Lin (1991). This instrument has 20 items, and can investigate the attitudes and awareness of students in studying science. It is suitable for middle school students. This instrument was found to have both good content validity (Mattheis *et al.*, 1985) and high reliability of Cronbach coefficients: Mattheis *et al.* (1985), α=0.95 and Takemura *et al.* (1985), α=0.94.

D. The Science Activities Questionnaire (SAQ)

"SAQ", formerly developed by Mattheis *et al.* (1985) and then translated by Lin (1991), was administered in this study to understand students' extra-curricular science activities. This instrument was found to have both good content validity (Mattheis *et al.*, 1985) and high reliability of Cronbach coefficients: Mattheis *et al.* (1985), α=0.91 and Takemura *et al.* (1985), α=0.86. It is composed of 29 test items and good for sampling middle school students' experience in extra-curricular science activities.

3. Procedures

After translation and rearrangement, all the test instruments were first evaluated and revised by several scientists, science educators, and schoolteachers, based on the objectives and contents. Subsequently, 119 students from all grades in Yan-Ming Junior High School were administered with those tests in the pilot study. The final version of test instruments was formally administered to students selected from 15 junior high schools in five areas in Taiwan. A total of 1892 subjects were included in the effective sample, with 609 7th graders (32.2%), 633 8th graders (33.5%) and 650 9th graders (34.3%).

Parental socioeconomic status was determined in terms of superior parental professions and educational levels according to two-factor indices proposed by Hollingshead (Lee, 1986). According to the professional index and the educational index, parental socioeconomic status was divided into 5 grades, Grade I is the highest, and Grade V is the lowest.

Descriptive statistics for each integrated science process skill and logical thinking ability were established. Correlations were calculated among integrated science process skills, logical thinking abilities, science attitudes, science activities, and socioeconomic status of parents.

III. Results and Discussion

1. Reliability of Instruments (Internal Consistency Mmeasured by Cronbach's Alpha)

The reliability of internal consistency, Cronbach's α of GALT, obtained by administering GALT to 1892 students in junior high schools, was 0.73, and it is in good agreement with Mattheis *et al.* (1985), α=0.77 ; and Takemura *et al.* (1985), α=0.73.

For TIPS II, an α value of 0.83 was got, which is very similar to other studies: Burns *et al.* (1985, α=0.86); Nakayama (1988, α=0.86); Mattheis *et al.* (1985, α=0.82); and Takemura *et al.* (1985, α=0.86).

Regarding SAS in this study, α value was calculated to be 0.92 and found to be the same as Mattheis *et al.* (1985, α=0.95) and Takemura *et al.* (1985, α=0.94).

Finally, SAQ had an α value of 0.88, reasonably close to the results of Mattheis *et al.* (1985, α=0.91) and Takemura *et al.* (1985, α=0.86).

In summary, all the four instruments were believed to be reliable because they had high internal consistency.

2. Logical Thinking

A. Mean Scores and Standard Deviations of Each Item in GALT

After GALT was administered to the 1892 students, the mean scores and standard deviations of each test item were computed and are shown in Table 1.

Clearly, the mean scores ranged between 0.03 and 0.80, and their standard deviations between 0.16 and 0.50. The whole test had an average of 4.28 (out of 12), with a standard deviation of 0.26. The mean score of Item 1 (conservation of mass) is 0.80 and Item 11 (combinational reasoning), 0.59. Other items have low mean scores, especially Item 9 and Item 10 (correlational reasoning) which have mean scores of 0.10 and 0.03 only, the lowest scores. It

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Table 1. Mean Scores and Standard Deviations of Each GALT item (N=1892)

Item number	mode of logical thinking	mean (range 0-1)	SD
1	Conservation (mass)	0.80	0.40
2	Conservation (volume)	0.47	0.50
3	Proportional	0.37	0.48
4	Proportional	0.35	0.48
5	Controlling variables	0.35	0.48
6	Controlling variables	0.31	0.46
7	Probabilistic	0.30	0.46
8	Probabilistic	0.39	0.49
9	Correlatioal	0.10	0.30
10	Correlational	0.03	0.16
11	Combinational	0.59	0.49
12	Combinational	0.22	0.42
GALT (all Items)		4.28 (range 0-12)	0.26

can be concluded that in logical thinking, Chinese junior high school students are doing well in concrete operational tasks of "conservation of mass", but they are poor in five formal operational reasoning abilities, among which correlational reasoning is the worst. Such findings are in good agreement with the results found among American junior high school students (Mattheis, 1985).

B. Sub-Test of Logical Thinking Ability

(a) All junior high school students

The mean scores, standard deviations, percentage of correct responses, and difficulty order for six modes of logical thinking (GALT) of all junior high school students are shown in Table 2.

Table 2 shows that the percentage of correct responses of sub-tests of logical thinking ability ranged from 6.4% (correlational reasoning with the lowest percentage of correct responses) to 62.6% (conservation of mass with the highest percentage of correct responses). The test items were arranged in increasing difficulty as follows: conservation of mass, combinational reasoning, proportional reasoning, probabilistic reasoning, controlling variables, and correlational reasoning. Junior high school students had the best percentage of correct responses of 62.6% in concrete operational tasks of "conservation of mass". As regards the four logical thinking abilities in the formal operational stage, controlling variables, probabilistic reasoning, proportional reasoning and combinational reasoning, their percentage of correct responses ranged between 32.8% and 40.8%, moderately good. But the percentage of correct responses of correlational reasoning is only 6.4%, the poorest of all. It is obvious that correlational reasoning is the most difficult type of logical thinking for junior high school students. This finding has been well supported by American and Japanese researchers (Mattheis *et al.*, 1985; Takemura *et al.*, 1985).

(b) Sex

The mean scores, percentage of correct responses, standard deviations, and t-test, for GALT (all test and sub-tests) analyzed by sex are shown in Table 3.

Among all their performances in the subtests, both male and female students have the best

Table 2. Mean Scores, Standard Deviations, Percentage of Correct Responses and Order of Difficulty for Modes of Logical Thinking (N=1892)

mode of logical thinking	no of items	mean (range 0-2)	SD	Correct response (%)	order of difficulty
Correlational	2	0.13	0.36	6.4	1 (most difficult)
Controlling variables	2	0.66	0.73	32.8	2
Probabilistic	2	0.68	0.83	34.2	3
Proportional	2	0.73	0.76	36.3	4
Combinational	2	0.82	0.76	40.8	5
Conservation	2	1.27	0.70	62.6	6 (easiest)
GALT (all)	12	4.28	0.26	35.7	

*Correct response (%) = ($\bar{X}$ ÷ no. of items) ×100

Table 3. Mean Scores, Percentage of Correct Responses, Standard Deviations and t-Test for GALT by Sex.

		GALT (all)	Conser.	Prop.	Con. Var.	Prob.	Corr.	comb.
No. of Items		12	2	2	2	2	2	2
Male	$\bar{X}$	4.60 (Range 0-12)	1.38 (Range 0-2)	0.85 (Range 0-2)	0.62 (Range 0-2)	0.74 (Range 0-2)	0.16 (Range 0-2)	0.86 (Range 0-2)
	SD	2.77	0.71	0.79	0.73	0.85	0.40	0.77
	Corr. Res. (%)	38.4	69.0	42.4	31.1	37.0	7.75	43.1
Female	$\bar{X}$	4.02 (Range 0-12)	1.19 (Range 0-2)	0.63 (Range 0-2)	0.68 (Range 0-2)	0.64 (Range 0-2)	0.11 (Range 0-2)	0.78 (Range 0-2)
	SD	2.51	0.66	0.72	0.74	0.81	0.31	0.75
	Corr. Res. (%)	33.5	59.3	31.4	34.2	32.0	5.25	38.9
	t	4.74	6.06	6.25	-1.87	2.60	2.96	2.41
	P (2-tailed)	0.000	0.000	0.000	0.061	0.009	0.003	0.016

Correct response (%)=($\bar{X}$ ÷ no. of items) ×100

Male: N_1=841, Female: N_2=1051

scores in "conservation of mass", the second in "combinational reasoning", and the worst in "correlational reasoning". Male students had better scores in "proportional reasoning", but female students scored better in "controlling variables".

The t-test showed that there is a significant difference (P<0.001) between the mean scores of male students ($\bar{X}$=4.60) and female students ($\bar{X}$=4.02) in the whole test of logical thinking ability. In the sub-tests of "conservation of mass" and "proportional reasoning", males are significantly higher than females (P<0.001). In the sub-tests of "probabilistic reasoning" and "correlational reasoning", males are also significantly better than females (p<0.01). Likewise, males are significantly better than females in "combinational reasoning" (P<0.05). In "controlling variables", while the mean score of female students is higher than that of male students, there is no significant difference between the two scores.

(c) Grades

The mean scores, standard deviations, percentage of correct responses, and ANOVA for GALT (all test and sub-tests) analyzed by grades, are shown in Table 4.

Table 4 indicates that students in all three grades have the highest percentage of correct responses in "conservation of mass", the second in "combinational reasoning" and the lowest in "correlational reasoning".

Based on the results from the analysis of variance, it was found there was a significant difference between the mean scores of different graders (P<0.001) in both GALT and its sub-tests. Posteriori comparisons by the Scheffe method demonstrated that in all the above measurements except "correlational reasoning" there were significant differences between any two grade students (P<0.05). As for the mean scores in "correlational reasoning", the only significant difference was found between 9th grade students and 7th grade students (P<0.05).

(d) Cognitive developmental levels

Based on the classification of Roadrangka et al. (1983), GALT scores from 0-4 are considered as the concrete operation stage; scores from 5-7 are the transitional operation stage; scores from 8-12 are the formal operation stage. The numbers of each grade student in every cognitive developmental level are shown in Table 5.

It is shown clearly in Table 5 that the proportion of concrete operational students in each grade decreases with higher grades, but the proportion of transitional operational and formal operational stu-

Table 4. Mean Scores, Standard Deviations, Percentage of Correct Responses and ANOVA for GALT by Grades

		GALT (all)	Conser.	Prop.	Con. Var.	Prob.	Corr.	comb.
No. of Items		12	2	2	2	2	2	2
7th	$\bar{X}$	3.07 (Range 0-12)	1.05 (Range 0-2)	0.46 (Range 0-2)	0.41 (Range 0-2)	0.48 (Range 0-2)	0.10 (Range 0-2)	0.57 (Range 0-2)
	SD	2.13	0.68	0.62	0.60	0.73	0.30	0.71
	Corr. Res. (%)	25.6	52.7	22.8	20.6	24.0	5.50	28.6
8th	$\bar{X}$	4.34 (Range 0-12)	1.29 (Range 0-2)	0.70 (Range 0-2)	0.69 (Range 0-2)	0.70 (Range 0-2)	0.12 (Range 0-2)	0.84 (Range 0-2)
	SD	2.56	0.69	0.75	0.76	0.83	0.34	0.75
	Corr. Res. (%)	36.1	64.4	35.1	34.3	35.1	5.85	42.2
9th	$\bar{X}$	5.37 (Range 0-12)	1.46 (Range 0-2)	1.00 (Range 0-2)	0.86 (Range 0-2)	0.86 (Range 0-2)	0.16 (Range 0-2)	1.02 (Range 0-2)
	SD	2.68	0.63	0.79	0.75	0.87	0.41	0.76
	Corr. Res. (%)	44.7	73.2	50.1	42.9	43.1	8.15	50.9
	F	136.3741	59.5783	90.4765	63.0304	35.2960	5.5697	57.9161
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Posteriori Comparisons (Scheffe′ method)		7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–9th	7th*–8th 8th*–9th 7th*–9th

*$p<0.05$
7th. grade: N_1=609, 8th. grade: N_2=633, 9th. grade: N_3=650
Correct response (%)=($\bar{X}$ ÷ no. of items)×100

Table 5. Developmental Levels by School Year

Developmental level	7th. grade		8th. grade		9th. grade		All	
	N	%	N	%	N	%	N	%
Concrete (0-4scores)	470	77.2	352	55.6	249	38.3	1071	56.6
Transitional (5-7scores)	114	18.7	195	30.8	247	38.0	556	29.4
Formal (8-12scores)	25	4.1	86	13.6	154	23.7	265	14.0
Total	609		633		650		1892	

dents increases with higher grades. However, in each grade, concrete operational students are in greater proportion while formal operational students are in smaller proportion. In the whole sample, 1071 students are concrete operational (56.6%), 556 students are transitional operational (29.4%) and only 265 students are formal operational (14.0%).

(e)The correlational analyses between logical thinking and science attitudes, science activities out of school, as well as parental socioeconomic status are shown in Table 6.

As is shown in Table 6, for all the sample students, the correlation coefficients between logical ability and science attitude, science activities, parental socioeconomic status are 0.18, 0.09 and

Table 6. Coefficients of Correlation between GALT and Science Attitude, Science Activities, and Socioeconomic Status of Parents

		Science attitude	Science activities	Socioeconomic status of Parents
	GALT	0.18 ***	0.09 ***	0.15 ***
GALT	Male	0.21 ***	0.10 **	0.14 ***
	Female	0.12 ***	0.05	0.16 ***
GALT	7th grade	0.16 ***	0.02	0.16 ***
	8th grade	0.23 ***	0.03	0.15 ***
	9th grade	0.30 ***	0.19 **	0.19 ***
GALT	Concrete	0.08 **	0.04	0.09 ***
	Transitional	0.04	0.10 **	0.05
	Formal	0.09	0.05	0.04

*** $p<0.001$, **: $p<0.01$ (1-tailed test)

0.15 respectively and they are positively and significantly correlated ($P<0.001$). In the case of both male and female students, their logical thinking is significantly correlated with science attitudes and parental socioeconomic status ($P<0.001$), correlation coefficients for males being 0.21 and 0.12, correlation coefficients for females being 0.14 and 0.16. And male students were found to have a positive and significant correlation ($r=0.10$) between logical thinking and science activities at 0.01 level.

The correlation coefficients between logical thinking and science attitudes, and parental socioeconomic status of students are: 7th graders, 0.16 and 0.16; 8th graders, 0.23 and 0.15; and 9th graders, 0.30 and 0.19. They are all positively and significantly correlated ($P<0.001$). For 9th grade students, the correlation coefficient between logical thinking and science activities is 0.19 and they are positively and significantly correlated ($P<0.001$).

In terms of cognitive developmental levels, it was also found that, In the case of concrete operational students, their logical thinking is significantly correlated with both science attitudes and parental socioeconomic status: $r=0.08$, $P<0.01$ for the former; and $r=0.09$, $P<0.001$ for the latter. Transitional operational students are found to have positive and significant correlation between their logical thinking and their science activities, with $r=0.10$ and $p<0.01$.

In summary, for all the sample students, if they have better attitudes towands science, more activities and higher parental socioeconomic status, then they have better logical thinking.

3. Science Process Skills

A. Mean Score and Standard Deviation of Each Item of Science Process Skill Test (TIPS II)

The mean score and standard deviation of each item of all science process skills test (TIPS II) are shown in Table 7.

Table 7. Mean Score and Standard Deviation of Each TIPS II Item (N=1892)

Item number	$\bar{X}$ (range 0-1)	SD	Item number	$\bar{X}$ (range 0-1)	SD
1	0.75	0.43	19	0.67	0.47
2	0.43	0.50	20	0.54	0.50
3	0.75	0.43	21	0.53	0.50
4	0.69	0.46	22	0.44	0.50
5	0.50	0.50	23	0.56	0.50
6	0.41	0.49	24	0.34	0.48
7	0.31	0.46	25	0.51	0.50
8	0.23	0.42	26	0.37	0.48
9	0.62	0.49	27	0.10	0.30
10	0.55	0.50	28	0.45	0.50
11	0.34	0.47	29	0.15	0.49
12	0.66	0.47	30	0.48	0.50
13	0.60	0.49	31	0.56	0.50
14	0.68	0.47	32	0.46	0.50
15	0.44	0.50	33	0.54	0.50
16	0.25	0.43	34	0.33	0.47
17	0.67	0.47	35	0.31	0.46
18	0.52	0.50	36	0.48	0.50
TIPS II	17.50 (range 0-36)	6.43			

From Table 7, it can be seen the mean scores of individual items were generally moderate except Item 27 (Mean Score=0.10) and Item 29 (Mean Score=0.15) which belong to "identifying and stating hypotheses". The mean score of the whole test was 17.50 (out of a total of 36). Further analysis of students' response patterns showed that students focused on the facts only, but they didn't have the skills of formulating and identifying hypotheses, so they could not solve problems like Item 27 and Item 29. As regards the work of Mattheis (1985) in American junior high schools, their students also got a mean score of 0.01 in Item 27. Therefore, it be can concluded that both Chinese and American junior high school students are poor at "identifying and stating hypotheses".

B. Science Process Skills of Junior High School Students

(a) All junior high school students

Mean scores, standard deviations, correct response percentage and order of difficulty, for five science process skills (TIPS II) of all junior high school students, are shown in Table 8.

The data in Table 8 show that among the five skills of the integrated science process, Chinese junior high school students performed best in "identifying variables" (percentage of correct responses=57.7%) but performed worst in "identifying and stating hypotheses" (percentage of correct responses=41.6%). Since the percentage of correct responses of all integrated science process skills didn't range widely away from the middle point (mean percentage of correct responses is nearly 45%), it is reasonable to conclude Chinese junior high school students have acquired moderate and equal efficiency in five integrated science process skills.

Besides, the performances of Chinese junior high school students in five integrated science process skills were ranked in the following decreasing order: identifying variables (easiest), designing investigations, graphing and interpreting data, operationally defining and identifying and stating hypotheses (most difficult). This finding is exactly the same as in Takemura's (1985) work in Japanese junior high schools.

(b) Sex

Mean scores, standard deviations, correct response percentage and t-test, for TIPS II (all and sub-tests) by sex are shown in Table 9.

It was found in Table 9 that both male and female students had the highest percentage of correct responses in "identifying variables" but the

Table 8. Mean Scores, Standard Deviations, Percentage of Correct Responses and Order of Difficulty for Science Process Skills (N=1892)

Process skills	Item number	$\bar{X}$	SD	Corr. resp. (%)	Order of difficulty
Identifying and stating hypotheses	4,6,8,12,16 17, 27, 29, 35.	3.74 (range 0-9)	1.66	41.6	1 (most difficulty)
Operationally defining	2, 7, 22, 23, 26, 33.	2.66 (range 0-6)	1.54	44.3	2
Graphing and interpreting data	5,9,11, 25, 38, 34.	2.75 (range 0-6)	1.50	45.8	3
Designing investigations	10, 21, 24.	1.43 (range 0-3)	0.96	47.6	4
Identifying variables	1, 3, 13, 14 15, 18, 19, 20 30, 31, 32, 36.	6.92 (range 0-12)	2.81	57.7	5 (easiest)
TIPS II (all)	36 items	17.50 (range 0-36)	6.43	48.6	

Correct response (%)=($\bar{X}$ ÷ no. of items) ×100

Table 9. Mean Scores, Standard Deviations, Percentage of Correct Response and t-Test for TIPS II by Sex

		TIPS II (all)	Sta. hypo.	Ide. var.	Oper. def.	Desi. inv.	Graph.
Male (N_1=841)	$\bar{X}$	17.24 (range 0-36)	3.72 (range 0-9)	6.63 (range 0-12)	2.70 (range 0-6)	1.42 (range 0-3)	2.77 (range 0-6)
	SD	7.02	1.79	2.94	1.63	0.96	1.57
	Corr. res. (%)	47.9	41.4	55.3	45.0	47.2	46.2
Female (N_2=1051)	$\bar{X}$	17.70 (range 0-36)	3.76 (range 0-9)	7.16 (range 0-12)	2.62 (range 0-6)	1.44 (range 0-3)	2.73 (range 0-6)
	SD	5.91	1.55	2.69	1.47	0.96	1.44
	Corr. res. (%)	49.2	41.7	59.6	43.7	48.0	45.5
No. of items36		9	12	6	3	6	
t		-1.51	-0.41	-4.00	1.09	-0.58	0.61
P (2-tailed)0.130		0.685	0.000	0.274	0.565	0.540	

Corr. res. (%)=($\bar{X}$ ÷ no. of items) ×100; Sta. hypo.: Identifying and stating hypothesis, Ide. var.: Identifying variables, Oper. def.: Operationally defining, Desi. inv.: Designing investigations, Graph.: Graphing and interpreting data.

lowest percentage of correct responses in "identifying and stating hypotheses". Both sexes also had the same ranking order for the percentage of correct responses of other integrated science process skills. After analyzing the differences of mean scores between sexes in the integrated science process skills test by t-test, no significant differences were detected between sexes except that female students ($\bar{X}$=7.16) performed significantly better than male students ($\bar{X}$=6.63) in "identifying variables".

(c) Grades

Mean scores, standard deviations, correct response percentage and ANOVA for TIPS II (all and sub-tests) by grades, are shown in Table 10.

An inspection of Table 10 shows us that students of each grade all had the highest percentage of correct responses in "identifying variables". The poorest performances varied for different graders: 7th graders in "operationally defining", 8th graders and 9th graders in "identifying and stating hypothesis" respectively. After applying the ANOVA method to the mean scores of TIPS II and its sub-tests, the following results were found: for mean scores: 9th grade students>8th grade students>7th grade students, and there were significant differences between them ($P<0.001$); for posteriori comparisons by the Scheffé method: among TIPS II and five sub-tests of TIPS II, there were significant differences ($P<0.05$) between different graders with 9th grades, the best and 7th graders, the worst, except that in the sub-test of "identifying and stating hypotheses" where a significant difference at 0.05 level was detected between 9th graders and 8th graders, and 7th graders only.

To sum up, students improved their skills in integrated science processing because of more opportunity to learn science which is associated with promoting grades.

(d) Cognitive developmental level

Mean scores, standard deviations, correct response percentages and ANOVA for TIPS II (all and sub-tests) by developmental level rank of junior high school students are shown in Table 11.

As can be seen from Table 11, whatever cognitive stages students might be, they performed best in "identifying variables". Concrete operational students had the lowest percentage of correct responses in "operationally defining", and the

Table 10. Mean Scores, Standard Deviations, Percentage of Correct Responses and ANOVA for TIPS II by Grades

		TIPS II (all)	Sta. hypo.	Ide. var.	Oper. def.	Desi. inv.	Graph.
No. of items		36	9	12	6	3	6
7th. grade (N_1=609)	$\bar{X}$	15.19 (range 0-36)	3.44 (range 0-9)	6.04 (range 0-12)	2.27 (range 0-6)	1.17 (range 0-3)	2.29 (range 0-6)
	SD	5.60	1.59	2.68	1.42	0.92	1.34
	Corr. Res. (%)	42.2	38.2	50.3	37.8	39.0	38.1
8th. grade (N_2=633)	$\bar{X}$	16.94 (range 0-36)	3.53 (range 0-9)	6.84 (range 0-12)	2.50 (range 0-6)	1.38 (range 0-3)	2.69 (range 0-6)
	SD	6.27	1.59	2.72	1.51	0.97	1.52
	Corr. Res. (%)	47.1	39.3	57.0	41.7	45.9	44.8
9th. grade (N_3=650)	$\bar{X}$	20.19 (range 0-36)	4.23 (range 0-9)	7.83 (range 0-12)	3.17 (range 0-6)	1.72 (range 0-3)	3.24 (range 0-6)
	SD	6.36	1.68	2.75	1.55	0.91	1.46
	Corr. Res.	56.1	47.0	65.2	52.9	57.4	54.0
F		109.6365	45.3202	68.8024	62.6270	56.8235	69.4268
P		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Posteriori Comparisons (Scheffe' method)		7th*–8th 8th*–9th 7th*–9th	8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th	7th*–8th 8th*–9th 7th*–9th

*$p<0.05$, Corr. res. (%)=($\bar{X}$ ÷ no. of items) ×100

second to the lowest percentage of correct response in "identifying and stating hypotheses". Transitional operational and formal operational students had the lowest percentage of correct responses in "identifying and stating hypotheses", and the second to the lowest percentage of correct responses in "operationally defining". Despite the cognitive developmental levels, students all had difficulty in the skill of "identifying and stating hypotheses" and "operationally defining" but they found "identifying variables" to be an easy integrated science process skill. The percentage of correct response of TIPS II and its sub-tests indicated that the order of proficiency in integrated science process skills is : formal operational students>transitional operational students >concrete operational students.

Analysis of variance showed that the mean scores of formal operational students in "TIPS II" and its sub-tests were better than those of transitional operational students and the mean scores of transitional operational students in "TIPS II" and its sub-tests were better than those of concrete operational students. There were significant differences between those mean scores (P<0.001). Posteriori comparisons by the Scheffé method also witnessed such differences (P<0.05). Therefore, it is natural to conclude that students improved their integrated science process skills when they developed from one cognitive stage to another stage.

4. The Correlational Analysis between Science process Skills and Science Attitude, Science Activities and Parental Socioeconomic Status

The result of correlation analysis between junior high school students' science process skills and science attitude, science activities and parental socioeconomic status are shown in

Table 11. Mean Scores, Standard Deviations, Percentage of Correct Responses and ANOVA for TIPS II by Developmental Level Rank

		TIPS II (all)	Sta. hypo.	Ide. var.	Oper. def.	Desi. inv.	Graph.
No. of items		36	9	12	6	3	6
Concrete (N_1=1071)	$\bar{X}$	14.28 (range 0-36)	3.15 (range 0-9)	5.73 (range 0-12)	2.10 (range 0-6)	1.10 (range 0-3)	2.19 (range 0-6)
	SD	4.94	1.47	2.48	1.30	0.87	1.34
	Corr. Res. (%)	39.7	35.0	47.8	34.9	36.8	36.6
Transitional (N_2=556)	$\bar{X}$	20.06 (range 0-36)	4.21 (range 0-9)	7.92 (range 0-12)	3.07 (range 0-6)	1.67 (range 0-3)	3.19 (range 0-6)
	SD	5.44	1.48	2.47	1.54	0.92	1.35
	Corr. Res. (%)	55.7	46.7	66.0	51.2	55.7	53.2
Formal (N_3=265)	$\bar{X}$	25.13 (range 0-36)	5.14 (range 0-9)	9.65 (range 0-12)	4.05 (range 0-6)	2.24 (range 0-3)	4.05 (range 0-6)
	SD	4.60	1.57	1.92	1.31	0.74	1.26
	Corr. Res.	69.8	57.1	80.4	67.4	74.7	67.5
F		593.0318	228.9041	348.8273	250.1770	214.4421	250.6685
P		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Posteriori Comparisons (Scheffe' method)		Conc*–Tran Tran*–Form Conc*–Form	Conc*–Tran Tran*–Form Conc*–Form	Conc*–Tran Tran*–Form Conc*–Form	Conc*–Tran Tran*–Form Conc*–Form	Conc*–Tran Tran*–Form Conc*–Form	Conc*–Tran Tran*–Form Conc*–Form

*$p<0.05$

Table 12.

From Table 12, it can be seen the correlation coefficients between integrated science process skills and science attitude ranged from 0.14 to 0.30, in terms of the whole sample, different sexes, different grades and concrete operational level. They were positively correlated and significant ($p<0.001$). For transitional operational students, significant and positive correlation was also found between their science process skills and attitude to science ($r=0.13$, $p<0.01$). It can be clearly stated that for various categories of students except formal operational ones, the better their attitude towards science, the better their integrated science process skills.

Among all the subjects, for male students and 9th grade students, there were positive and significant correlations between their integrated science process skills and science activities (r ranged from 0.08 to 0.15, $p<0.001$). In other words, the data from all students, male students and 9th graders showed that more science activities will make their integrated science process skills better.

Among the whole sample, in both sexes, all grades and concrete operational students, the correlation coefficients between integrated science process skills and parental socioeconomic status ranged from 0.17 to 0.23. They were found to have positive and significant correlations ($p<0.001$). This result indicated that all categories of students, except transitional operational and formal operational ones, had better science process skills if they had higher parental socioeconomic status.

5. The Correlation between Integrated Science Process Skills and Logical Thinking

Table 12. Correlation Coefficents between TIPS II and Science Attitude, Science Activities and Parental Socioeconomic Status

			Science Attitude	Science Activity	Socioeconomic Status of Parents
TIPS II	All students		0.21 ***	0.08 ***	0.18 ***
	Sex	Male	0.30 ***	0.12 ***	0.20 ***
		Female	0.14 ***	0.06	0.17 ***
	Grades	7th. grade	0.21 ***	0.06	0.23 ***
		8th. grade	0.24 ***	0.01	0.18 ***
		9th. grade	0.30 ***	0.15 ***	0.20 ***
	Developmental level	Concrete	0.14 ***	0.06	0.19 ***
		Transitional	0.13 **	0.03	0.04
		Formal	0.12	0.02	0.14

**p<0.01, ***p<0.001, 1-tailed test

The correlational analysis results between the integrated science process skills and logical thinking are shown in Table 13.

In the following categories of students: the whole sample, female and male students, 7th graders through to 9th graders, concrete operational students, transitional operational students and formal operational students, their integrated science process skills were found to be positively and significantly correlated (p<0.001), with the correlation coefficient ranging between 0.26 and 0.71. Such a fact shows that integrated science process skills are closely related to logical thinking. That is to say, the better logical thinking abilities students have, the better their integrated science process skills; and vice versa.

Table 13. Correlation Coefficients between GALT and TIPS II

			GALT
TIPS II		All students	0.67 ***
	Sex	Male	0.71 ***
		Female	0.65 ***
	Grades	7th. grade	0.55 ***
		8th. grade	0.65 ***
		9th. grade	0.68 ***
	Developmental level	Concrete	0.37 ***
		Transitional	0.26 ***
		Formal	0.42 ***

***p<0.001, 1-tailed test

IV. Conclusion

In the six modes of logical thinking, Chinese junior high school students performed worst in "correlational reasoning" but performed best in "conservation of mass". Their performances in different tasks can be ranked in the following order : "conservation of mass", "combinational reasoning", "proportional reasoning" "probabilistic reasoning", "controlling variables" and "correlational reasoning". Significant differences have been detected between sexes in the following variables: "GALT", " conservation of mass", "proportional reasoning", "probabilistic reasoning", "correlational reasoning" and "combinational reasoning" (p<0.05, p<0.01 or p<0.001 respectively).

It was also found that there were significant differences at 0.05 level between different grades in GALT as a whole and the individual subtests of logical thinking, except in "correlational reasoning". This demonstrated that higher grade students have better logical thinking ability and the number of formal operational students increases with the increasing grades.

In addition, their logical thinking ability was positively correlated at a significant level (p<0.001) with "attitude to Science", "science activities" and "socioeconomic status of parents". In other words, those students who have better a attitude to science, more science activities and higher socioeconomic status of parents have better logical thinking abilities.

Among the five integrated science process skills, Chinese junior high school students were best in "identifying variables" but poorest in "identifying and stating hypotheses". Their performances can be arranged in the following order:" identifying variables", "designing investigations", "graphing and interpreting data", "operationally defining" and "identifying and stating hypotheses".

The only significant difference was detected between sexes in "identifying variables" ($p<0.001$) and no differences were found between male and female students in other science process skills.

Regarding "TIPS II" and its component integrated science process skills, except in "identifying and stating hypotheses", significant differences have been found among different grade students ($p<0.05$). It indicated that students improved their integrated science process skills as they advanced to higher grades.

Students with different developmental levels have best performances in "identifying variables" among the various skills of the science process. Concrete operational students experienced the greatest difficulty in "operationally defining" and "identifying and stating hypotheses". Transitional and formal operational students were poorest in "identifying and stating hypotheses".

As a whole, formal operational students got the highest scores, transitional operational students the second highest, and concrete operational students, the lowest in "TIPS II"and its sub-tests.

The integrated science process skills of junior high school students were positively correlated with attitude to science, science activities and parental socioeconomic status at a 0.001 level of significance.

From the above findings, it can be concluded that the integrated science process skills of junior high shcool students were positively correlated with their logical thinking at a significant level ($p<0.001$) in terms of grades, sexes and cognitive developmental levels. In other words, integrated science process skills were closely correlated with logical thinking ability.

References

Allen, T. E. (1978). Comment on "An investigation of two formal operational schemata in adolescents enrolled in ISCS classrooms". *Journal of Reserch in Science Teaching, 15*, 179-182.

Ankney, P. & Joyce, L. (1974). The development of a Piagetian paper-and-pencil test for assessing concrete-operational reasoning. Unpublished doctoral dissertation, University of Northern Colorado.

Baired, W. E. & Borich, G. D. (1985). Validity considerations for the study of formal reasoning ability and integrated science process skills. Paper presented at the annual meeting of National Association for Research in Science Teaching, French Lick Springs, La. (ERIC Document Reproduction Service No. ED 254 428).

Bitner, B. L. (1987). The GALT: A measure of logical thinking ability of 7th through 12th grade students. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington, DC. (ERIC Document Reproduction Service No. ED 293 717).

Bitner, B. L. (1988a). Logical and critical thinking abilities of sixth through twelfth grade students and formal reasoning modes as predictors of critical thinking abilities and academic achievement. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, Mo. (ERIC Document Reproduction Service No. ED 293 715).

Bitner, B. L, (1988b). Is the GALT a reliable instrument for measuring the logical thinking abilities of students in grades six through twelve? Paper presented at the annual meeting of the National Association for Research in Science Teaching. Lake of the Ozarks, Mo. (ERIC Document Reproduction Service No. ED 293 716).

Burney, G. M. (1974). The construction and validation of an objective formal reasoning instrument. Unpublished doctoral dissertation, University of Nothern Colorado.

Burns, J. C., Okey, J. R., and Wise, K. C. (1985). Development of an integrated process skill test: TIPS II. *Journal of Research in Science Teaching. 22*(2), 169-177.

Cohen, H. G. (1980). Dilemma of the objective paper-and-pencil assessment within the Piagetian framework. *Science Education, 64*, 741-745.

Dillashaw, F. G. & Okey, J. R. (1980). Test of intergated science process skills for secondary science students. *Science Education, 64*, 601-608.

Inhelder, B. & Piaget, J. (1958). The growth of logical thinking: From children to adolescence. New York: N.W. Norton and Company.

Klinckmann, E. (1963). The BSCS grid for test analysis. *BSCS Newsletter, 19*(20), 1963.

Klopfer, L. E. (1971). Evaluation of learning in science, in handbook on formative and summative evaluation of student learning. Bloom, Hasting, and Madaum, Eds, New York: McGrawHill.

Lawson, A. E. (1978). The development and validation of a Classroom Test of Formal Reasoning. *Journal of Reserch in Science Teaching. 15*, 11-24.

Lawson, A. E., Karplus, R., & Adi, M. (1978). The acquisition of propositional logic and formal operational schemata during the secondary school years. *Journal of Research in Scicnce Taching. 15*, 465-478.

Lee, Kuen-Chorng (1986). A study on the evaluation of the mental need of college students in Taiwan. Unpublished master's thesis, Graduate School of Guidance, Taiwan College of Education. (in Chinese).

Lin, J. L. (1991). A study on the logical thinking abilities and the integrated science process skills of gifted students in junior high schools. (in Chinese). *Journal of National Changhua University of Education Vol. 2*, 335-379.

Lin, J. L. and Jeng, B. Y. (1991). A study on science process skills and its predictors among junior high school gifted students in Taiwan. (in Chinese). *Journal of National Changhua University of Education, Vol. 2*, 381-415.

Lin, J. L. (1992). A study on the development of molecular concepts and instruction with diagnostic evaluation for students in Taiwan (1) A study on the relationships between the understanding of molecular concepts and problem solving for students in Taiwan. (in Chinese). *Journal of National Changhua University of Education, Vol. 3*, 407-478.

Longeot, F. (1965). Analyse statistique de trios tests genetiques collectifs. *Bulletin de l' Institut National D'Etude. 20*(4), 219-237.

Ludeman, R. R. (1974). Development of the Science Process Test (SPT). *Dissertation Abstracts International*. 36, 203-A, (Doctoral dissertation, Micthigan State University, 1974) (University Microfilms No. 75-14,783).

Manzano, Virgilio U. (1986). Factors in science education correlates of adolescent students' logical thinking skills in the Phillippines and Japan. Doctoral desertation, Hiroshima University.

Mattheis, Floyd E., Coble, C., and Spooner, William E. (1985). Descriptive statistics of a study of reasoning skills in junior high school students for North Carolina, US-Japan cooperative research project (1984-1985), unpublished paper, Science/Mathematics Education Center, East Carolina University, April.

Mattheis, Floyd E. (1986). A study of the logical thinking skills of junior high school students in North Carolina and Japan. Paper presented at the World Council for Curriculum and Instruction's Fifth Triennial World Conference on Education, Hiroshima, Japan.

McLeod, R. J., Berkheimer, G. D., Fyffe, D. W., & Robinson, R. W. (1975). The development of criterion-validated test items for four integrated science processes. *Journal of Research in Science Teaching, 12*, 415-421.

Molitir, L. L. & George, K. D. (1976). Development of a test of science process skills. *Journal of Research in Science Teaching, 13*, 405-412.

Nakayama, G. (1988). A study of the relationship between cognitive styles and integrated science process skills. Paper presented at the National Association for Research in Science Teaching Annual Meeting, Missouri, LD.

National Assessment of Educational Progress (NAEP,1969). Science Objectives, Ann Arbor, Mich: committee on assessing the progress of education.

National Science Teachers Association (NSTA,1964). Theory into action-A guide to science curriculum development. Washington, D. C.; NSTA.

Padilla, M. J., Okey, J. R., & Dillashaw, F. G. (1983). The relationships between science process skills and formal thinking abilities, *Journal of Research in Science Teaching, 20*(3), 239-246.

Preece, P. F. W. (1978). Associative structure and the schemata of proportionality. *Journal of Research in Science Teaching. 15*, 395-399.

Raven, R. (1974). Programming Piaget's logical operations for science inquiry and concept attainment. *Journal of Research in Science Teaching, 11*, 251-261.

Riley, J. W. (1972). The development and use of a group process test for selected processes of the science curriculum improvement study. Dissertation Abstracts International. 33 6200A-6201A (Doctoral dissertation, Michigan State University, 1972) (University Microfilms No. 73-12, p.807).

Roadrangka, V., Yeany R. H., & Padilla, M. J. (1983). The construction and validation of Group Assessment of Logical Thinking (GALT). Paper presented at the annual meeting of the National Association for Research in Science Teaching. Dallas, TX.

Shymanskey, J. A., Kyle, W. C. Jr., & Alport, J. M. (1983). The effects of new science curricula on student performance. *Journal of Research in Science Teaching, 20*(5), 387- 404.

Takemura, Shigekazu et al. (1985). A study of reasoning skills in junior high school students (grade 7-9). The Japan-U.S. cooperative science program (1984-1985). unpublished paper, Science/Mathematics Education Center, East Carolina University and Hiroshima University, Apirl.

Takemura, S., Matsumoto, K., Hioki, M., and Matsumoto, S. (1987). Logical thinking, process skills, and science educational factors in junior high school students. (in Japanese). Paper presented at the 37th. annual meeting of the Japanese Association for Science Education at Shiga University, August.

Tannenbaum, R. S. (1968). The development of the test of science process. *Dissertation Abstracts International, 29*, 215-A (Doctoral dissertation, Columbia University, 1968) (University Microfilms No, 69-677).

Tobin, K. G. & Capie, W. (1980). The development and validation of a group test of logical thinking. A paper presented at the annual meeting of the American Educational Research Association, Boston, Massachusetts, April.

Tobin, K. G. & Capie, W. (1982). Development and validation of a group test of integrated science process. *Journal of Research in Science Teaching. 19*, 133-141.

Walbesser, H. H. (1965). An evaluation model and its application. Washington, DC: The American Association for the Advancement of Science, AAAS., Miscellaneous Publication No. 65-9.

我國國中學生的邏輯思考與統整科學過程技能

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摘　要

本研究以邏輯思考團體測驗（GALT），統整科學過程技能測驗II（TIPS II），科學態度量表（SAS）與校外科學活動問卷（SAQ）等四種評量工具，研究我國國中學生（N=1892）的邏輯思考與統整科學過程技能。邏輯思考與統整科學過程技能在「性別」、「年級」與「認知發展水準」之間的差異，分別採用t-考驗或變異數分析考驗。邏輯思考，統整科學過程技能，科學態度與科學活動之間的相關也做了研究。茲將研究結果簡述如下：

⑴全部國中學生的GALT與TIPS II的平均數與標準差分別爲4.28，17.50與0.26，6.43。達於形式操作期的學生數，隨著年級的升級的升高而增加。⑵除「性別」外，還輯思考與統整科學過程技能在「年級」及「認知發展水準」之間的差異，達於顯著水準。⑶統整科學過程技能在「性別」之間的差異，未達於顯著水準，但是邏輯思考在「性別」之間的差異達於顯著水準。⑷邏輯思考與統整科學過程技能分別與「科學態度」、「科學活動」、「父母社經地位」之間均有正相關。

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A Study on Task Analysis for Engineering Drawing Technicians

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ABSTRACT

The purpose of this study was to identify the essential working items for various levels of engineering drawing technicians in the future. It included task items analysis and operation items analysis.

To achieve the purpose of the study, empirical methods and techniques were used, such as field interviews, field questionnaires, scholars' meetings and the Delphi technique etc. to accurately access the task and operation items of various technicians. The participants in this empirical study included 32 technicians, 7 content specialists and 7 professors who teach engineering drawing and design.

Through the study, we have concluded that task items of engineering drawing technicians are 25 and their operation items are 16. Task items of design technicians are 23 and their operation items are 19. This information can be used as a comparison for the curriculum content edited by the Ministry of Education. In addition, it can be provided as a reference for the screening and selecting of teachers, training in Employment & Vocational Training Administration, and also on-the-job training in industry.

Key words: Engineering Drawing, Task Analysis, Task Items, Operation Items, Drawing Technicians, Design Technicians.

I. Introduction

Based on the National Construction Six-Year Projects proposed by the Department of Economic Reconstruction, we must depend on machinery as the basic foundation among key expert techniques such as supporting delicate machinery, automating enterprises, aerospace and anti-pollution industries, etc.. Then this is combined with optic and electricity technologies to fulfill the national project developments. Therefore, during the process of enhancing automated enterprises, in addition to maintaining hardware as the equipment of automation, it is also necessary to promote technicians' knowledge and ability. And engineering drawing ability is acknowledged publically as one of the basic techniques (Earle,1991). As for the enterprise aspect, the engineers' and technicians' graphicl drawing ability plays a primary and important role, and has a direct and profound influence on the quality of our national engineering construction.

Currently, training organizations for Taiwan's engineering drawing technicians include Job-training Centers, Vocational Industrial Senior High Schools, Colleges, Universities etc.. Regarding every organization's adoptive texts and machinery equipment, as before the training they didn't investigate the field analysis, it always leads to the result that training techniques are disconnected from industrial needs, and the learning can't be fitted to practical use. Also, a lack of systematical techniques in lectures and projects, and no organized criteria among various training units, causes students difficulty in absorbing what they have learned, not to mention the impossibility of arranging a proper career. Therefore, we urgently need to develop a task analysis method to analyze the qualifications and knowledge needed by engineering drawing and design technicians.

The motivation of this study on the vocational analysis of engineering drawing is to efficiently solve the problems in the techniques for training experts on engineering drawing and design. It can achieve the purpose of promoting our engineering drawing technicians' skill standards and as the basic criteria for management of lectures on cultivating skilled manpower for engineering drawing and design techniques.

Based on the above motivation, the study's main purpose was to analyze the work of various engineering drawing technicians, including task items and operation items, in order to analyze, organize and develop the qualification and knowledge needed by engineering drawing and design technicians.

II. Methods

In the study, analysis of the task and operation items was made by actual visits, field questionnaires, experts meetings, Delphi and scholars' meetings etc., to understand the task and operation items of technicians of different levels. The process was as follows:

1. Reviewing the Related Literature

First, occupational analysis, knowledge construction and research papers, etc.. and all relevant theories to organize the occupational task/operation items were collected for the basic foundation of the study.

2. Planning Task Analysis Modules

The operation modules were divided into four sections: planning, communication, controlling and paperwork. And each section was arranged into five steps: analysis, design, development, application, and adjustment. According to the task analysis modules and procedures, the operation control list was drawn up.

3. Criteria of investigation of organizations were confirmed, based on the organizations' operation status. (such as: capital revenue, number of employees)

4. Analysis of Investigated Organization's Technicians

To confirm the relevant levels' technicians as visiting or investigation objectives.

5. Collecting Technicians' Working Data

Gathering information on various technicians' working skills or operation procedures, etc. to be the criterion for developing the working items questionnaire.

6. Developing the Working Items Questionnaire

The information gained from Step 5 was still insufficient to cover all the task items. Therefore, we needed to develop the working items questionnaire for further checking.

7. Questionnaire Filling, Actual Visiting and Interviews.

8. Developing Checking Lists

Organizing the results of the field visits and investigation, and editing the working items review list for the experts' meeting on surveying working items.

9. Confirming the Invited Experts

Based on Tersine and Rigts (1976), the experts who participate in Delphi, in addition to professional knowledge and practical skills in the discussed fields, must also have fair and objective judgment ability; the most important point is that they must be sincere, enthusiastic and willing to take part in the entire procedure. In order to achieve the goal, that our designed task items and contents of engineering drawing could satisfy the demands of industry, the experts included senior engineering drawing teachers of various schools and training units, as well as engineering drawing professionals and operational practical experts from industry. Therefore, our study chose well-known and representative manufacturers for the field visits and field investigations in order to understand the actual operation status and the professional ability of manufacturers' mechanical drawing technicians, and also to request their participation in Delphi, so as to add their names to the reference list. Next, according to the above screening criteria, we arranged a working groups meeting to confirm the final representatives.

10. Experts Meeting

The object of the experts meeting was to discuss the suitability and completion of all the task, operation, and design items, and to share ideas on the procedures and related limitations of practicing Delphi.

11. Practicing Delphi

Delphi is a specific technique to make use of a series of questionnaires, to gather a group of experts from all fields, and through a systematic communication procedure to gain those experts' views on the problems. Such a technique can provide a much more accurate estimation, judgement and prediction of future events. It has mostly been used on decisive simulation, lecture development and campus design etc. since 1960. That's why, during the study, not only did we actually visit manufacturers and conduct field investigations and experts' meetings, but also we used the Delphi technique to confirm the necessary task and operation items for engineering drawing technicians to compensate for anything missed in the experts' meetings and field investigations.

The purpose of the first Delphi was to ensure the suitability and completion of engineering drawing and design which were prepared by study groups and the necessary working/operation items of engineering drawing technicians. Meanwhile, we requested the experts to mark the essential operation items, focusing on each task item, in order to ensure the adopted items were fitted to the necessary ability of engineering drawing technicians.

The goal of the second Delphi was to provide the opportunity for all the participating experts to share opinions. And we again judged whether the second investigation papers' working/operation items were indeed necessary for engineering drawing technicians. We also requested the experts to mark the essential operation items, focusing on each task item, in order to ensure the adopted items were fitted to the necessary ability of engineering drawing technicians.

The purpose of the third Delphi was the same as the second Delphi. The investigation papers were reorganized from the results of the second Delphi.

12. Correcting Working Items Check List.

13. Writing Reports

14. Printing Reports

III. Findings and Conclusions

The study used actual visits and a field questionnaire on occupation analysis, and also thoroughly screened and organized the opinions and suggestions of experts from industrial enterprises, focussing on the study's necessary task/operation items list for engineering design and drawing technicians. We eventually drew up a task/operation items list. Therefore, the theory and techniques of occupational analysis can be used to manage the necessary working items in future projects of Taiwan's engineering drawing and designing technicians in Taiwan.

(I) After organizing the industrial experts' and workers' opinions and suggestions, we have concluded that there are 25 essential task items, and 16 operation items for engineering drawing technicians.

1. Task Items for Engineering Drawing Technicians:

The task items include the total 25 working drawings(Figure 1) of screw, spring, gear, chain wheel, cam, pulley, rachet, flying wheel, shaft, rolling parts, rotating parts, sleeve parts, silent parts, other standard machinery, body, base, supporting parts, metal board products, plastic products, products made from other materials, fusing connections, rivet connections, developments, piping and tubing, fixtures and dies, etc.. The above 25 task items were divided into working graphics and professional graphics. And working graphics were further divided into three subgroups: detail drawing, assembly drawing, and exploded pictorial drawing.

2. Necessary Operations of Task Items for Engineering Drawing Technicians:

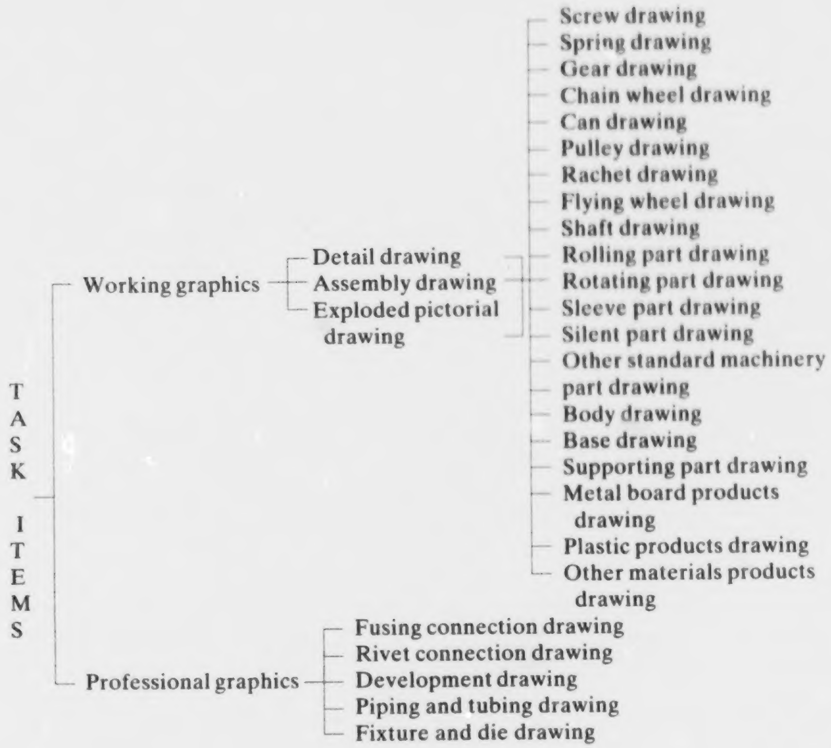
TASK ITEMS
Working graphics
Detail drawing
Assembly drawing
Exploded pictorial drawing
Screw drawing
Spring drawing
Gear drawing
Chain wheel drawing
Can drawing
Pulley drawing
Rachet drawing
Flying wheel drawing
Shaft drawing
Rolling part drawing
Rotating part drawing
Sleeve part drawing
Silent part drawing
Other standard machinery part drawing
Body drawing
Base drawing
Supporting part drawing
Metal board products drawing
Plastic products drawing
Other materials products drawing
Professional graphics
Fusing connection drawing
Rivet connection drawing
Development drawing
Piping and tubing drawing
Fixture and die drawing

Figure 1. Task items for engineering drawing technicians.

There are 16 operation items(Table 1): geometry drawing, orthographic projection drawing, sectional view drawing, auxiliary view drawing, pictorial view drawing, dimensioning, marking surface finishing marks, tolerance specification, marking surface treatment, standard machinery drawing, sketching, measuring, filling part list, filling alternation column, filling topic column, and checking reference data, etc..

Table 1. Necessary operations of task items for engineering drawing technicians

geometry drawing
orthographic projection drawing
sectional view drawing
auxiliary view drawing
dimensioning
marking surface finishing marks
tolerance specification
marking surface treatment
standard machinery parts drawing
sketching
measuring
filling part list
filling alternation column
filling topic column
checking reference data

(II) According to the experts' suggestions and conclusions, there are 23 essential task items, and 19 operation items for design technicians.

1. Task Items for Design Technicians:

There are a total of 23 design parts (Figure 2): spring, gear, chain wheel, cam, pulley, rachet, flying wheel, circling shaft, silent shaft, rolling parts, rotating parts, silent parts, body, base, supporting parts, metal board products, plastic products, products made from other materials, fusing connections, rivet connections, developments, fixtures and dies, etc.. The above task items can be divided into working graphics and professional graphics. And the working graphics are detail drawing, assembly drawing and exploded pictorial drawing.

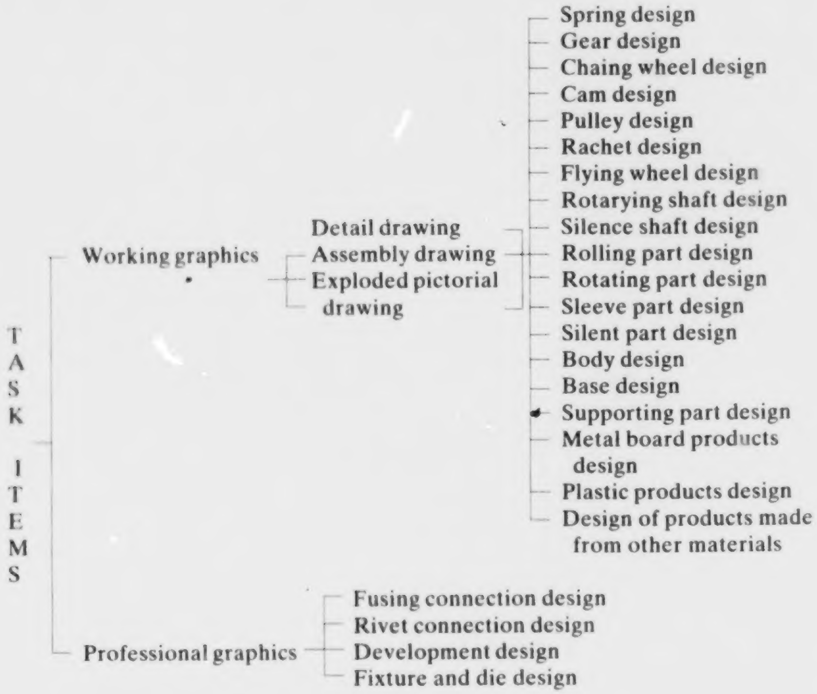
TASK ITEMS
Working graphics
Detail drawing
Assembly drawing
Exploded pictorial drawing
Spring design
Gear design
Chaing wheel design
Cam design
Pulley design
Rachet design
Flying wheel design
Rotarying shaft design
Silence shaft design
Rolling part design
Rotating part design
Sleeve part design
Silent part design
Body design
Base design
Supporting part design
Metal board products design
Plastic products design
Design of products made from other materials
Professional graphics
Fusing connection design
Rivet connection design
Development design
Fixture and die design

Figure 2. Task items for engineering design technicians.

2. Necessary Operation Items for Design Technicians:

There are 19 operation items: designing tolerance, designing surface roughing, designing surface treatment, designing geometric tolerance, selecting standard machinery parts, selecting machinery materials, calculating the referent values of standard machinery, designing leak prevention systems, designing lubrication systems, analyzing founding quality, analyzing material quality, selecting view sights, marking key measures, analyzing model processing quality, structure design, structure analysis, designing error prevention instruments, applying monopoly protection, and analyzing manufacturing procedures.

IV. Recommendations

We have provided the following suggestions for the reference of people in every field and for scholars offering further study on the task analysis of technicians' knowledge.

Table 2. Necessary operations of task items for engineering designing technicians

designing tolerance
designing surface roughing
designing surface treatment
designing geometric tolerance
selecting standard machinery parts
selecting machinery materials
calculating the referent values of standard machinery
designing leak prevention systems
designing lubrication systems
analyzing founding quality
analyzing material quality
selecting view sight
marking key measures.
analyzing modeling processing quality
structure designing
structure analysis
designing error prevention instruments
applying monopoly protection
analyzing manufacturing procedures

1. In establishing the occupational work contents for various technicians, in addition to collecting the relevant papers, actual visits and investigation papers, we also need the proof modules of the Delphi technique or a similar system in order to successfully approach the problem of actual necessary working contents for technicians in different vocations.
2. Before every educational institution or school screens and selects teachers, it can make use of Delphi's methods and techniques to confirm the teachers' required knowledge and ability to meet its individual educational needs.
3. In editing all schools' lecture summaries or topics, Delphi can also provide an idea of the students' required knowledge and techniques for meeting student's mental and physical needs, as well as students' present or future work requirements.
4. When creating the criteria for examination techniques, Delphi can point out the necessary knowledge and techniques of technicians of various levels.
5. The task analysis has a great deal of reliability. It can also be referred to as a basis for knowledge building for other technicians.

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References

Earle, J. H. (1991). Drafting Technology. New York: Addison-Wesley Publishing Company.

Tersine, R. J., & Rigts, W. E. (1976). The Delphi technique: A long range planning tool. *Business Horizons, 19*(2), 51-55.

Task Analysis for Engineering Drawing

我國機械製圖業技術人力所需工作分析之研究

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摘　　要

本研究旨在採討未來六年我國機械製圖業技術人力所需工作分析之研究。爲達研究目的，本研究採實施訪查法、問卷調查法、專家座談與Delphi等實徵方法，以確定各層級技術人員之工作項目、操作項目與設計項目。

本研究實徵對象爲產業界各層級技術人力實地工作者共32名、資深專業實務專家七人及任教機械製圖與機械設計學者七人。經分析實徵、整理歸納分別得製圖技術人力工作項目二十五項與操作項目十六項，並得設計技術人力工作項目二十三頸與操作項目十九項。這些資料除可供教育部編輯課程標準參考外，尙可供學校教師甄選、技能檢定以及職業訓練中心與產業界在職訓練之參考。

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The Effects of CAI on Elementary Students' Mathematics Achievement of Different Cognitive Styles/Locus of Control

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ABSTRACT

The purposes of this study were (1) to compare the mathematics achievements of students using computer-assisted instruction as well as traditional instruction; (2) to compare the relationships between student achievement, cognitive styles, locus of control, and teaching strategies; (3) to compare student attitude concerning mathematics and computers and (4) to determine the students' attitudes as to degree of acceptance of the computer-assisted instruction.

The sample comprised 174 5th grade students in total. Among them, eighty-eight students accepted two hours of computer-assisted instruction after they had finished unit instruction, and the other eight-six students accepted two hours traditional testing/explanation instruction after they had finished unit instruction.

The results revealed that there were no significant differences in mathematics achievement and attitude,in different cognitive styles, or in locus of control while using different teaching strategies. There was an interaction between cognitive styles and teaching strategies, and a significant difference existed in computer attitude on teaching strategies. It was noted that students showed a positive attitude towardscomputer-assisted instruction. This study proposed more suggestions for educational authorities, schools and teachers.

Key words: Field-dependent-independent, locus of control, computer-assisted instruction course, traditional instruction, mathematics achievement, mathematics attitude, computer attitude

I. Instruction

1. Research Motivation

Computer-Assisted Instruction (shortened as CAI) is the integration of modern engineering and educational technology. Through the practice of CAI, the teaching material is directly introduced via interactions with the computer, and we can use it to control individualized educational environments in the teaching process. As to its functioning in individualized and remedial instruction, both domestic and overseas educators all agree that it is quite valuable (Li Chin Pao, 1983; Chen Chiao-Hsiung, 1988). However, in order to attain the ideal of the art of teaching, in which instruction should be given according to the student's ability via individualized instruction on CAI, not only do the characteristics of teaching materials have to be taken into consideration, but also the characteristics of learners. In this way, learners' individual differences should be given thought so that CAI can be implemented with the upmost efficiency. As the latest research has pointed out, student characteristics will affect CAI's results (Caffarella et al.,1980; Duty & Giltrow, 1987). Therefore, it is necessary to evaluate learner characteristics firstly to promote CAI development and futher that CAI may be effectively applied and controlled.

Domestic and overseas research regarding individual differences or adaptation to individual differences have usually taken cognitive ability (such as intellect) as the one aptitude variable for individual differences. Personal cognitive ability is unipolar, value directional, distributed from low to high, and therefore cognitive ability can be high or low, good or bad. But the cognitive style among personal cognitive characteristics is the habit of processing information, and shows the typical personal style (Messick, 1976) in the cognitive processes of personal perception, thinking, problem-solving and memorization. Cognitive style is bipolar, value differentiated, distributed from one end to another, is relatively spread from one style to another instead of from high to low, and has nothing to do with good or bad (Messick, 1976; Witkin,et al., 1977). Therefore, cognitive style, as compared to cognitive ability, can explain the essence of the teaching process more appropriately. Science cognitive style is value differentiated, which can prevent making value judgements and lessen the unfavorable effects on students.

Ever since the field dependence theory of cognitive style was presented by H. A. Witkin, it has widely received attention from psychologists. The study of field dependence starts from the study of conception and extends to the study of mental activity; it is found that field dependence is related to conceptional differential ability and mental function. Hence, it is essential in the study of education and guidance. Many researches have shown field dependence is related to the student's major, electives chosen, work inclination, choice in job and academic performance (Tin Chen-Feing, 1987).

According to Social-Learning Theory, Rotter finds that people have different opinions as to the relationship between their behavior and goal. Some people believe that their achievements are all due to the efforts they have made and the responsibility they pay for their behavior, and therefore success or failure is all controlled by oneself. These people can thus predict and control the events that happen in their lives. This kind of inclination belongs to a belief in internal control, (abbreviated as IC); on the other hand, some people believe their achievements are alln subject to outside influence, and have nothing to do with their behavior, responsibility or efforts. Success or failure is all decided by other people, or is beyond one's control, or furthermore is all caused by fortune, chance or destiny, and is beyond what this person can predict or control. This kind of inclination belongs to a belief in external control (abbreviated as EC) (Chou Kan-Feng, 1985).

The result of Hersch & Scheibe (1967) found that the person who possesses belief in internal control tends to have better achievements in patience, control, sociality, intellect, and performance in achievement than those processing belief in external control. The person with belief in internal control believes he is more self-determined, goal-achievable, powerful, independent, efficient, and diligent. The person with an IC tendency tends to adjust himself better, while one with an EC tendency usually has a sense of powerlessness and frustration and tends to antagonistic and aggressive (Hamsher, Galler, & Rotter, 1968; Clouser & Hjelle, 1970). The person with an IC tendency will make efforts to control his environment to achieve goals, and meanwhile can control inner impulses. Of course educators all agree that an IC or EC tendency is only a matter of difference in degree (Phares, 1965; Seeman & Evans, 1962; Seeman, 1963; Straits & Sechrest, 1963).

In the past, the relevant CAI research in our country placed emphasis on the composition of software or on the efficiency evaluation of CAI. Study has rarely been made concerning the effects achieved when CAI is applied to students with different cognitive characteristics or with different personalities. Yet from the above statement, it can be realized that personal field dependence and locus of control play an important role in respect to personal motive, behaviour performance and academic achievement, etc. Therefore, it is necesary to look into the efficiency made on CAI through personal cognitive characteristics and personality characteristics so that the most appropriate teaching style can be supplied according to different student characteristics. Only through the above can "individual differences" be adapted to and the ideal of "teaching according to the student's ability" can be reached.

Based on the above motive, the main objectives for this research are as follow

(1) Compare the influence on math achievement made by using traditional instruction concerning different field dependence & locus of control, with that using CAI among elementary school students, in order to supply students

with different cognitive characteristics and personality characteristics for more appropriate extracurricular guidance.

(2) Determine the difference made in math attitude and computer attitude after students have received different experimental treatment.

(3) Determine if elementary school students like to learn with the application of CAI.

2. Reseach Hypotheses

The followings are the reaearch hypotheses:

(1) After eliminating intellect and math achievement test T1 scores, there would be an interaction between experimental treatment and field dependence in the math achievement test T2.

(2) After eliminating intellect and math achievement test T1 scores, there would be an interaction between experimental treatment and locus of control in the math achievement test T2.

(3) After experimental treatment, students in the CAI group would get higher scores in math achievement tests T2 than those in the traditional instruction group after eliminating the influence of the score of the intellect and math achievement test T1.

(4) After experimental treatment, the post-test score on math attitude of the CAI group students would be higher than that of traditional instruction group after eliminating the pre-test score.

(5) After experimental treatment, the post-test score on computer attitude of the CAI group students would be higher than that of the traditional instruction group after eliminating the pre-test score.

3. Limitations of the Research

This research was affected by the supply of manpower, time, and other objective factors beyond our full control. It was also subject to the limitations below:

(1) This research took 5th graders in 4 classes from an elementary school in Tainan County as experimental subjects, and therefore the inference on research outcome has some limits.

(2) The factors of students receiving extracurricular guidance, or using reference books and test paper from book stores might affect the internal and external validity. Although before the experiment, the researcher asked teachers to advise students not to attend extracurricular guidance, or to use reference books, or test papers during the experiment, as well as to keep a record of those students violating these rules so that they could be eliminated when processing the data, it was hard to have these factors under full control.

(3) This research adopted CAI software developed by the computer center of the Ministry of Education, Taiwan Provical Institute for Elementary School Teachers' Inservice Education and some computer companies, and therefore students might have used this teaching software before. This possibility might have had an influence upon the internal validity of the experiment.

(4) The research was to solidify the application of ready-made software to elementary school CAI, and therefore ready-made software was used. Although the software used for this research has been evaluated, the quality of each software was inconsistent, and this might affect the internal validity of the experiment.

(5) In this research, the field independent/dependent students and students with belief in internal/external control were divided via the average score that all subjects got on the "Group Imbedded-Figure Test" and "Children Internal/External Control Aptitude Scale". As the subject number chosen for the experiment was low, it is difficult to determine those subjects who possessed an extreme score, which might also affect the interanal validity of the experiment.

II. Methods

1. Subject

For convenience of administrative coordination, as well as the teaching experiment, computer facilities and manpower assistance, this research picked at random 174 students from 4 classes of the 5th grade in Kuan-Miao elementary school in Tainan County as experimental subjects and randomly selected among them 2 classes as the experimental group where students were to take a CAI course, and left the other 2 classes as a control group where students would take traditional instruction. None of these students had had computer experience. The subjects were divided into "field dependent", "field-independent" and the types of "external conrol" and "internal control". Among them, the field independents' score was higher than the average score (8.92) gotten by the subjects on the "Group Imbeded-Figure Test" and the field independents' score on the "Group Imbeded-Figure Test" was lower than the average gotten by all the students. IC type students' score on the "Children Internal/External Control Aptitude Scale" was higher than the average score (24.68) of all the students. EC type students' score on the "Children Internal/External Control Inclination Scales" was lower than average. The following was the distribution of number of students, mean, and standard deviation on field dependence and locus of control.

2. Research Design

The design of this research was based on the "nonequivalent control-group quasi-experiment research" design. The research subjects were 4 classes of students chosen from the 5th grade in the Kuan-Miao elementary school in Tainan County. Two classes were randomly chosen as the experimental group, and the other two classes constituted a control.

Differences the subjects have in their intellect and their original mathematics achievement might interfere with the effects of the experiment. The scores of both are taken as covariances. This influence will be eliminated via some statistically controlled methods. Therefore the research adopted "2 (teaching method) × 2 (field dependence)" and "2 (teaching method) × 2 (locus of control)". The 2 factors of analysis of covariance were used to test if there was interaction between experimental treatment and aptitude and whether the effect from different experimental treatments was the same or not.

The following are explanations of research variables:

(1) Independent Variables

A. Instructional Method

According to the different teaching methods, subjects are divided into a computer-assisted instruction group and a traditional instruction group. These 2 groups both took the mathematics course taught by the original teacher, based on the instruction hours including 6 units: "Factors", "Multiples", "Quadrilaterals", "Area of a parallelogram", "Fractions" and "Addition & subtraction of fractions". Both teachers graduated from Department of Mathematics Education, Tainan Teacher's College. One of them has eleven years teaching experience and the other has five. For the CAI group, in addition to the mathematics course, the students took 2 periods of the CAI course, which was taught by the researcher using the off-time during lunch breaks or group activities. In these courses the researcher only played the role of eleminating software/hardware problems and maintaining classroom discipline and did not give lectures or perform any teaching activity with the students. For the students in the traditional instruction group,in addition to the mathematics course, the students also took a math course where the original teacher additionally gave an ordinary quiz in one period and corrected the quiz in another period for every experiment unit. The teach-

Table 2-1. The Distribution Number of Subjects on Field-Dependent/Independent

	Experimental Group (N=88)		Control Group (N=86)	
	Field Dependent	Field independent	Field Dependent	Field Independent
Number of subjects	56	32	32	54
Mean	4.64	13.13	4.59	13.43
SD	2.55	3.28	2.49	4.28

Table 2-2. The Distribution of Number of Subjects on Locus of Control

	Experimental group (N=88)		Controlled Group (N=86)	
	EC	IC	EC	IC
Number of subjects	44	44	42	44
Mean	21.32	27.78	21.12	28.36
SD	2.73	1.99	2.26	2.98

ing content of both the computer-assisted instruction group and traditional instruction group were the same, and the teaching content were designed by the researchers according to the curriculum teaching manual.

B. Field Independent

The subjects were divided into field independent and field dependent groups according to the scores they got on the "Group Imbeded-Figure Test".

C. Locus of Control

Subjects were divided into internal control and external control based on scores gotten from the "Children Internal/External Control Aptitude Scale".

(2) Dependent Variables

A. The score of math achievement test T2.
B. The post-test score from math attitude scales.
C. The post-test score from computer attitude scales.

(3) Controlled Variables

A. Intelligence
This is the score the subject got from the "Orlay Psychological Ability Test" (as covariance).
B. The score gotten from math achievement test T1 (as covariance).
C. The pre-test score gotten form the math attitude scale (as covariance).
D. The pre-test score gotten from the computer attitude scale (as covariance).
E. Time for instruction

The instruction time spent on each unit was based on the teacher's manual. The synthesis and application (1), (2) was only done through the theacher's instruction instead of being done through experimental treatment. The unit title and instruction period were as shown on table 2-3

(4) The Instructional Material

The instructional material chosen by the researcher includes 6 units: factors, multiples, quadrilaterals, parallelogram area, fractions, and addition & subtration of fractions. These are based on the instruction activities in the "Instructional Guidance of Elementary School of Elementary School Math Volume 9", which was edited by the Institute for Compilation and Translation. The teachers in experimental and control groups all proceeded with instruction according to the listed contents of instructional activity and teaching time. The units that the two groups receiving experimental treatment studied were as table 2-4 shows:

3. Research Instruments

The instruments of the research were:

(1) Group Embeded-Figure Test

The test was revised by Wu Yu-yi from the original "Group Embeded-Figure Test" developed by Oltman, Raskin & Witkin (1971). It is a speed test including 3 parts, and a total of 25 questions.

(2) Child Internal/External Control Aptitude Scale

The scale was revised by Huang Chen-ho based on the "Nowichi-Strickland Children's Locus of Control Scales" by Nowichi Jr. and Strickland. There were 40 questions, each followed by answering yes/no. The higher the score, the more inclined to internal control the subject will be; the lower the score, the more inclined to external control the subject will be.

Table 2-3. Instruction Unit & Teaching Time

Instruction unit	factors	multiples	synthesis & applications (1)	quadrilaterals
Instruction period no.	7	7	3	6
	area of a parallelogram	fractions	addition & subtration of frctions	synthesis & applications (2)
Instruction period no	7	7	7	2

Table 2-4. Experimental Units

(1) Triangles
(2) Decimal numbers
(3) Factors
(4) Multiples
1st monthly examination
(5) Quadrilaterals
(6) Area of a parallelogram
(7) Fractions
(8) Addition and Subtraction of fractions
2nd monthly examination
(9) A rough estimation
(10) Area of triangle & trapezoid
(11) Equilateral polygons
(12) Straight squares
(13) Symmetry
3rd monthly examination.

Experimental unit

(3) Otis-Lennon Mental Ability Test (level 4)

The test was revised by Ying-Hao Chen and Wu Yu-Yi from the "Otis-Lennon Mental Ability Test". The original test was evolved from the "Otis Quickscoring Mental Ability Test", which was first published in the middle of 1930 and published again in 1968.

This test fits the use of 4th, 5th and 6th graders in elementary school. The test time is 45 minutes, and in addition to the time for guidance and explanation, the whole process could be completed within an hour.

(4) Mathematics Attitude Scale

The original Mathematics Attitude Scale was revised from Fennema and Sherman's "Fennema-Sherman Mathematics Attitude Scale" re-edited and translated by Mo-Ying Li (1983). There were 108 questions on the original scale, which is composed of 9 sub-scales. Four out of nine sub-scales, namely "Confidence in Learning with Math", "Practicality of Math", "Motivation in Investigating Math" and "Attitude to Math Success" were adopted. There were 12 questions from each sub-scale, 48 questions all together. It employed a 5-point scale in which the testee put a check on the elective item. In accordance with testee's comment "Strongly agree", "Agree", "No comment", "Disagree", and "Strongly Disagree", 5, 4, 3, 2, or 1 points will be given in the order of "Strongly Agree" to "Strongly Disagree" for the obverse-direction questions; One to five points will be given in the above order for reverse-direction questions. The higher the score is, the better and the more active math attitude is. The names of sub-scales and the obverse/reverse-direction questions are listed on table 2-5

Table 2-5. Obverse/Reverse-Direction Questions for Math Attitude Sub-Scales

Name of Sub-scale	Obverse-Direction Question	Reverse-Direction Question
Confidence in Learning Math	1, 5, 9, 13, 17, 21	25, 29, 33, 37, 41, 45
Practicality of Math	2, 6, 10, 14, 18, 22	26, 30, 34, 38, 42, 46
Motivation in Investigating Math	3, 7, 11, 15, 19, 23	27, 31, 35, 43, 47
Attitude toward Math Success	4, 8, 12, 16, 20, 24	28, 32, 36, 40, 44, 48

(5) Computer Attitude Scale

This scale was revised from Mei-Chun Yin's "Computer Attitude Scale" by the researcher. It is divided into 3 sub-scales: " Confidence in Computer", "Educational Application of Computer", " Practicality of Computer". There are 8 questions for each sub-scale, 24 questions in total. The obverse/reverse-direction questions for each sub-scales are as shown in table 2-6.

On this 5-point scale, student puts a check on an elective item in accordance with his/her own comment ranging form "Strongly Agree", "Agree", "No Comment", "Disagree", "Strongly disagree". Five points to one point will be given for the obverse-direction questions ranging from " Strongly Agree" to "Strongly Disagree". On the other hand, for reverse-direction questions, one point to five points will be given in the above mentioned order. The higher the score is,

Table 2-6. Obverse/Reverse-Direction Questions for Computer Attitude Sub-Scales

Name of Sub-scale	Obverse-Direction Question	Reverse-Direction Question
Confidence in Computer	1, 7, 13, 16, 22	4, 10, 19
Educational Application of Computer	2, 8, 11, 14, 20	5, 17, 23
Practicality of Computer	3, 6, 15, 18	9, 12, 21, 24

the more active and positive the computer attitude is.

The internal consistency of Cronbach's coefficient was 0.81,indicating the reliability of the scale was quite high.

(6) Mathematics Achievement Test T1

The test adopted was the "Mathematics Achievement Test for the Fourth Grade of Elementary School" edited by Taiwan Provincial Institute for Elementary School Teachers' Inservice Education. This math achievement test for elementary school is a single-subject achievement test based on a newly-edited math textbook. It is classified into 4 types which respectively measure math achievement for students in the first/second semester of grade 3 and 4.

There are 50 questions for each test, and 1-out-of 4 multiple choice questions were applied. The contents include mathematics concepts, calculations, and applications etc. It is a group test and the time spent on each volume was 50 minutes. All achievement tests were pencil-paper tests. Science question transcripts and answer sheets were separated, students had to write the answers on an answer sheet. One point was given once a question had been answered correctly. Points were not deducted if the answer was incorrect. The highest score for each volume was 50 points, the lowest one was 0.

This research adopted the test for the second semester of fourth grade. As for its reliability, test-retest reliability is 0.82 - 0.87; split-half reliability is 0.92.; Kuder-Richardson reliability is 0.91.; taking total record for the semester as a concurrent criterion, the concurrent validity was 0.77 - 0.81. In addition, the test established the percentile and T-score norm distribution for boys and girls students nationwide.

(7) Mathematics Achievement Test T2

This was adopted from the "Math Achievement Test" edited by the researcher according to the experimental unit. The test includes 6 units: factors, multiples, quadrilaterals, area of a parallelogram, fractions, and addition & subtraction of fractions. The editing process for the test was as below:

A. Editing Questions for Test

Consulting elementary school teaching guidance, volume 9, textbook, and drill, the researcher edited the questions for the test in 6 units. There were 12 questions for each unit, and seventy-two questions for test rehearsal have been completed.

B. Questions for Test Rehearsal

The test rehearsal was given to 208 students, including 5th graders from 3 classes chosen from the Chi-Chin elementary school in Kaohsiung City and 5th graders from 2 classes in Tainan County Kuan-Miao elementary school who had not participanted in the experiment. The time for test rehearsal lasted 85 minutes. After the rehearsal, four poorly-written questions were deleted by the researcher, and the test items then analysed using ITEMAN analysing software.

C. Question Transcript Edited

The formal questions for the test were chosen according to the analysis result of rehearsal questions. The standard for picking out the questions is point-biserial correlation over 0.30, difficulty index between 0.40-0.75, ~~and~~ an attempt to make the question difficulty index normally distributed. The number of questions for each unit is the same. The average level of difficulty of the test question scale was 0.61.

D. Validity and Reliability Test

The two-way specification table of Mathematics Achievement Test T2 is shown as table 2-7. After the formal test had been finished, four elementary school math teachers of fifth grade were asked to examine the questions of the test. They all agreed that the content validity of the test was quite high. As for reliability, the internal consistency of Cronbach's coefficient was 0.93, which is

Table 2-7. Two-way Specification Table of Mathematics Achievement Test T2

	Knowledge	Comprehension	Application	Analysis	total
1. Factors	1	5	1	1	8
2. Multiples	3	0	3	2	8
3. Quadrilateral	2	4	0	2	8
4. Area of a Parallelogram	2	3	3	0	8
5. Fractions	3	2	4	0	9
6. Addition & Subtration of Fractions	0	0	8	1	9
Total	11	14	19	6	50

considered quite good.

(8) Opinion Questionnaire of Computer Assisted Instruction

This questionnaire was revised in accordance with Wu Tieh-Hsiung's (1983; 1987) "Opinion Survey on CAI", Tang Tsun-Hui's (1987) " Students' Opinion Survey on CAI" and Tseng Chin-Ta's (1984) "Students' Opinion Survey on CAI". There are 22 questions in total on this opinion survey, which include two parts: "Opinions about Teaching software" and "Attitudes toward the CAI Model". Among them, question 1 to question 12 refer to opinions about teaching software and question 13 to question 22 refer to attitude toward the CAI instruction model.

The questionnaire employed a 5-point scale. The students in the CAI group put checks to mask their opinions after using CAI. Their opinions regarding teaching software and the CAI teaching model included "Strongly Agree", "Agree", "No Comment", "Disagree", "Strongly Disgree". Five to one points was given in the order from "Strongly Agree" to "Strongly Disagree".

This scale could only filled out after students in the CAI group had taken CAI. As there was no test rehearsal sample, factor analysis could not be performed. Through revision by CAI teaching expert, the expert reliability for the scale was established.

(9) Instructional Software:

The standards for software evaluation in this research were based upon the "Scrip Evaluation Reference Table of Computer-Assisted Instruction Course Software" edited by Rao Da-Chin and others commissioned by the Ministry of Education. These standards were divided into the three parts as " Common Evaluation", " Modeling Characteristics Evaluation " and " Subject Characteristics Evaluation ". The two parts " Common Evaluation" and " Mathematics Characteristic Evaluation " of " Subject Characteristic Evaluation " were adopted, and the researcher commissioned experts to examine Computer-Assisted Instruction Course Software developed by the Computer Center of the Ministry of Education, the Taiwan Provincial Institute for Elementary School Teachers' Inservice Education, and computer companies, and choose the most suitable instructional software experimental instruction units. Instructional software and the unit software adopted by this research are as follows: Factors (Ding Chi Technological Limited Co.) Multiples (Ding Chi Technological Limited Co.), Tetragons (Doctor Computer Software Programming Limited Co.), Parallelogram Area (Computer Center of the Ministry of Education), Fractions (UNALIS Corporation), and Addition & Subtraction of Fractions (Doctor Computer Software Programming Limited Co.). As evaluted by the math teachers, all of the CAI softwares are suitable for the content of math textbook. Besides, according to the responses of students in CAI groups, most of them think the CAI softwares are attractive and interesting, and they really can learn something from them.

4. Data Analysis

(1) Independent variables were based on group classification and field dependence and the dependent variable was based on grades of mathematics achievement test T2, which intelligence and mathematics achievement test T1 as covariance to proceed with analysis of covariance to examine Hypothese 1, 3.

(2) Independent variables were based on group classification and locus of control and the dependent variable was based on grades of mathematics achievement test T2, with intelligence and mathematics achievement test T1 as covariance to proceed with analysis of covariance to examine Hypothesis 2,3.

(3) The independent variable was based on group classification and the dependent variable was based on post-test grades of mathematics attitude and pre-test grades of mathematics attitude as covariance to proceed with analyais of covariance for examining Hypothesis 4.

(4) Independent variables were based on group classification, and the dependent variable was based on post-test grades of computer attitude, with pre-test grades of Computer attitude as covariance to proceed with analysis of Covariance for examing Hypothesis 5.

(5) After the implementation of "Opinion Questionnaire of CAI", investigation using percentage and accumulation of the result will be performed to understand the attitude toward CAI of the experimental group students.

III. Results and Discussion

1. Interaction of Experimental Treatment and Field Dependence on Student Mathematics Ahievement

As known from the " Summary of Experimental Treatment and field dependence,the intelligent and Mathematics Achievement Test T1 for each group for homogeneity test of regression on Mathematics Achievement Test T2" of table 3-1, the regression coefficient of F ratio is 1.65 (P>0.05), which cannot reject the hypothesis of homogeneity. Therefore the analysis of covariance was used to examine results after eliminating the effects of intelligence and mathematics achievement test T1 on mathematics achievement test T2, in order to test the effect of field dependence on students' mathematics achievement test T2.

After eliminating the effect of intelligence and mathematics achievement test T1, as shown on "The Analysis of Covariance Summary of Experimental Treatment and Field Dependence on Mathematics Achievement Test T2" of table 3-2, the interaction between experimenatl treatment and field dependence reached a significant difference (F=11.26, P<0.01); therefore, this hypothesis was accepted; to further examine its simple main effect, the result was as shown on " Simple Main Effects Analysis Summary of Field dependence and Experimental Treatment" of table 3-3, in which the mathematics achievement of different field dependence students in experimental and control groups has significant difference (F=5.80,p<0.05; F=3.89, p<0.05). Different experimental treatment also has a significant difference of field dependent and field independent students on mathematics achievement (F=4.03, p<0.05; F=7.36, p<0.01). In addition, knowing from the "Adjusted Mean Summary of Experimental Treatment, Field dependence on Mathematics Achievement Test T2" of table 3-4, the field dependent students attended CAI courses(M=33.18) performed better in mathematics achievement test T2 than field dependent students attending traditional instruction courses (M=29.77); but the performance on mathematics achievement test T2 of field independent students who attended CAI courses(M=28.44) was worse than field independent students who attended traditional instruction courses. This shows that field independent students are more suitable for traditional instruction courses.

Table 3-1. Summary of Experimental Treatment X Field Dependence of Intelligence, Mathematics Achievement Test T1 for Each Group for the Homogeneity Test of Regression of Mathematics Achievement Tet T2.

Source	SS	DF	MS	F	Sig of F
Between group (regression coefficient)	586.67	6	97.78	1.65	.138
Within groups	9625.40	162	59.42		

The possible reason for these results was that field independent students have their own unique recognition model and construction for getting knowledge. In other words, they develop a suitable method for themselves, and therefore, due to the CAI software which organized the method and content construction in advance, they did not perform as well as field dependent students which were short of ability to organize study material. This may be because knowledge construction represented on CAI software might be unaccordant or conflicting with the one that field independent students are used to, but it might help field dependent students who are short of organizing ability to build study constructions. As Kapadia (1987) pointed out, if CAI courses were organized for field dependent students and offered feedback for their representation, their representation would be improved; traditional instruction courses use the ordinary methods of test and review, in which teachers' methods for explaining subject aren't necessarity as constructive as CAI, but can offer answer techniques and items which should be noticed when answering, giving students more chances to use their own recognition construction and organize the main points; as Witkin & Goodenough (1981) pointed out, when teaching material are less constructive, learners have to orgnize by themselves. Field independent students can organize study material to form the needed construction, so they are more suitable for traditional instruction courses than field dependent students.

To further examine the main effects of each factor, table 3-2 shows that differences in mathematics achievement between field independent students and field dependent students were not significant (F=0.19, p>0.05) and the differences on the mathematics achievement test T2 between the experimental group and the control group also were not significant (F=0.33, p>0.05). This shows that after having experimental treatment and eliminating intelligence and the influence of students' prior mathematics grades, there were no differences in mathematics achievement between field independent students and field dependent students;

there were also no differences on the mathematics achievement test between experimental group which had received CAI courses and control group which had received traditional instruction courses.

2. Interaction of Experimental Treatment And Locus of Control on Students' Mathematics Achievement

As seen from the "Summary of Experimental Treatment and the Locus of Control, Intelligence, Mathematics Achievement Test T1 for each group for homogeneity test of regression on Mathematics Achievement Test T2" shown in table 3-5, regression coefficient of F ratio was 1.98 (p>0.05), which could not reject the hypothesis of homogeneity. Therefore, after eliminating the effect of intelligence, the analysis of covariance was used to examine mathematics achievement test T1 to mathematics achievement test T2, in order to test the effect of locus of control on students' mathematics achievement test T2.

As seen from the "The analysis of covariance Summary of Experimental Treatment, Locus of Control on Mathematics Achievement Test T2" shown in table 3-6, after eliminating the effect of intelligence and mathematics achievement test T1 on mathematics achievement test T2, interaction between experimental treatment and the locus of control didn't show significant difference (F=0.03, p>0.05), and therefore, the hypothesis cannot be accepted. The possible reason for this result was that the locus of control cannot infer students in anticipation of representing mathematics achievement on different experimental treatment and the " Children Internal/External Control Aptitude Scale" didn't include a lie detecting questionaire to detect whether students actually offered their own opinions or not when answering, and didn't include questions irrelevant to internal and external control to cover the real nature of scale. Therefore it was possible for students to answer in accordance with expectations of teachers and society in general, not according to relationship between behavior and reinforcement of inner personal and point of view they have in the real life. This made this research unable to divide group classification of student's internal and external control according to students' real internal and external control. In other words, there might be external control students in the internal control group, and internal control students in the external control group. Therefore, the result of the experiment was confused and made

Table 3-2. Aanalysis of Covariance Summary of Experimental Treatment, Field Dependence on Mathematics Achievement Test T2

Source	SS	DF	MS	F	Sig of F
Covariate	760.32	2	228.16	55.61	.000
Field dependence	11.82	1	11.82	.19	.660
Experimental treatment	20.26	1	20.26	.33	.564
Interaction	684.22	1	684.22	11.26	.001
Error	10212.07	168	60.79		

Table 3-3. Simple Main Effects Analysis Summary of Field Dependence and Experimental Treatment

Source	SS	DF	MS	F	Sig of F
Field dependence					
Experimental group	356.18	1	356.18	5.86	.017
Control group	236.20	1	236.20	3.89	.050
Experimental Treatment					
Field Dependent	244.67	1	244.67	4.03	.046
Filed Independent	247.29	1	247.29	7.36	.007
Eror	10212.07	168	60.79		

Table 3-4. Adjested Mean Summary of Experimental Treatment, Field Dependence on Mathematics Achievement Test T2

	Fidle Dependent	Field Independent	Total
Experimental group	33.18	28.44	61.62
Control group	29.77	33.26	63.03
Total	62.95	61.70	

Table 3-5. Summary of Experimental Treatment and Locus of Control for Intelligence and Mathematics Achievement Test T1 for Each Group for Homogeneity Test of Regression on Mathematics Achievement Test T2

Source	SS	DF	MS	F	Sig of F
Between groups (regression coefficient)	738.77	6	123.13	1.98	.072
Within group	10097.93	162	62.33		

interaction between experimental treatment and locus of control unable to reach a significant difference.

The further analyze main effects of each factor, from table 3-6 it can be found that main effects of different locus of control did not reach significant difference (F=1.14, p>0.05), and main effects of different experimental treatment also had no significant difference (F=0.18,p>0.05). It can be seen that, after eliminating the effect of intelligence and students' pre-test mathematics grades on post-testing of mathematics, there is no difference for internal control students and external control students on mathematics achievement, effect of locus of control for different experimental treatment was less than expected, and perhaps it appears that students answer according to the expectations of society when answering "Children Internal /External Control Aptitude Scale". After eliminating the effect of Locus of Control, there was no apparent difference between students of the experimental group receiving CAI courses and students of the control group receiving traditional instruction courses on representation of mathematics achievement. As seen from the "Adjusted Mean Summary of Experimental Treatment, Locus of Contorol on Mathematics Achievement Test T2", adjusted mean between experimental group (M=62.90) and control group (M=63.96) on mathematics achievement test T2 was quite small, and adjusted mean between external control (M=64.76) and internal control (M=62.10) students on mathematics achievement test T2 also was very small.

In this section, the main effects of experimental treatment didn't have any significant difference, which was the same result as the effect of experimental treatment and field dependence on students' mathematics achievement discussed in section 1. In other words, the main effects of experimental treatment after eliminating effects of locus of control and field dependence did not show significant difference, and therefore hypothesis 3cannot be accepted. The possible reason was because contents of course software were not good enough, which made mathematics achievement of CAI students worse than mathematics achievement of students of the traditional instruction group. It is also possible that students who were used to receiving tradition instruction at this point could not adopt themselves to the format of CAI at once, so the representation of students receiving CAI on mathematics achievement were worse than the representation of students receiving traditional instruction courses.

Table 3-6. The Analysis of Covariance Summary of Experimental Treatment, Locus of Control on Mathematics AchieveMent Test T2

Source	SS	DF	MS	F	Sig of F
Covariate	8586.25	2	4293.12	66.56	.000
Locus of Control	73.42	1	73.42	1.14	.288
Experimental treatment	11.75	1	11.75	.18	.670
Interaction	1.91	1	1.91	.03	.863
Error	10839.70	168	64.50		

Table 3-7. Adjusted Mean Summary of Experimental Treatment, Locus of Control on Mathematics Achievement Test T2

Source	External Control	Internal Control	Total
Experimental group	32.22	30.68	62.90
Control group	32.54	31.42	63.96
Total	64.76	62.10	

3. Effect Of Experimental Treatment On Students Mathematics Attitude

As seen from the "Homogeneity Test of Regression Summary of Mathematics Attitude's Pretest Grades of Experimental Group and Control Group on Post-test Grades" of table 3-8, the regression coefficient of F ratio was 0.90 (p>0.05), which could not reject the hypothesis of homogeneity. Therefore the analysis of covariance was used to examine the effect of experimental treatment on students' mathematics attitude, after eliminating mathematics attitude pre-test grades.

As seen in table 3-9, after experimental group and control group accepted assisted courses of different formats respectively, the mathematics attitude had no significant difference (p>0.5), and

Table 3-8. Homogeneity Test of Regression Summary of Mathematics Attitude's Pre-test Grades of Experimental Group and Control Group on Post-test Grades

Source	SS	DF	MS	F	Sig of F
Between groups (regression coefficient)	259.25	1	259.25	.90	.344
Within group	48905.39	170	287.68		

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Table 3-9. The Analysuis of Covariance Summary of Experimental Treatment on Mathematics Attitude's Post-test Grades

Source	SS	DF	MS	F	Sig of F	Groups	Adjusted Mean
Covariance	31853.30	1	31853.30			Experiemental	176.85
Between groups (Experimental Treatment)	151.58	1	151.58	.53	.469	Control	178.72
Within groups	49164.64	171	287.51				

therefore, the hypothesis could not be accepted.

Although the difference between experimental group and control group on mathematics attitude had no significant discrepancy, as seen from table 3-10 and 3-11, the difference in mathematics attitude before and after the experiment for both experimental group and control group were significantly different (Experimental group $p<0.05$, Control group $p<0.01$). Moreover, the difference in adjusted mean before and after the experiment of experimental group was -4.43, and the difference before and after the exeperiment for the control group was -5.14, which shows that after the experiment for both groups the mathematics attitudes were more active than before.

4. Effect Of Experimental Treatment On Students Computer Attitude

As seen from the "Homogeneity Test of Regression Summary of Computer Attitude's Pretest Grades of Experimental Group and Control Group on Post-test Grades" in table 3-12, the regression coefficient of F ratio didn't reach the level of signicificant difference ($F=17.09$, $p<0.01$), and therefore we could not say that the regression coefficeint of experimental group and control group had the same nature. Therefore, make the coefficient of the analysis of covariance of experimental treatment on computer attitude's post-test grades smaller ($p<0.01$) to avoid mistaken inference as far as possible.

As seen from table 3-13, after experimental group and control group received different instructional courses, computer attitude had significant difference ($F=15.48$, $p<0.01$), and adjusted mean of experimental group for computer attitude was 92.33, and control group's adjusted mean for computer attitude was 87.50. It can be said that after experimental treatment, computer attitude of experimental group was better than control group. Therefore, hypothesis 5 should be accepted.

5. Attitude Toward Computer-Assisted Instruction of Experimental Group Students

The attitudes of research subjects toward Computer-Assisted Instruction can be divided into two parts: one was opinions toward instruction software, and the other was attitude toward CAI's method. The questionnaire for opinions was only used on students of the experimental group which accepted CAI. The results are as shown below on table 3-14.

In respect to software design of teaching materials, subjects gave quite positive affirmation to all the questions. Among them, regarding software content design of teaching material, there were

Table 3-10. T-test Summary of Mathematics Attitude of Experimental Group before and after Experiment

Group	Numbers	Difference of mean	SD	DF	t	two-tailed test
Before-after experiment	88	-4.34	2.14	87	-2.03	.046

Table 3-11. T-test Summary of Mathematics Attitude of Control Group before and after Experiment

Group	Numbers	Difference of mean	SD	DF	t	two-tailed test
Before-after experiment	88	-5.14	1.67	85	-3.08	.003

Table 3-12. Homogeneity Test of Regression Summary of Computer Attitude's Pre-test Grades of Experimental Group and Control Group on Post-test Grades

Source	SS	DF	MS	F	Sig of F
Between groups (regression coefficient)	1013.61	1	1013.61	17.09	.000
Within group	10082.89	170	59.31		

87.7% of students who considered the explanation of computers to be orderly (question 2), 96.8% of students who considered that the examples listed on the computers could help them to study (question 3), and 88.6% who considered that they could learn something from CAI (question 7).

As to software feedback, most students considered that computers could point out erors and correct answers immediately, the manner of computers' responses were also very interesting (question 4, 5, 8), the content of instruction was very attractive (question 9), and the specific representation of teaching material could intensify impression (question 10).

From the point of view of operation, 93.1% of students considered that they could conveniently operate computers for studying (question 6), but for "I understand all the meaning of content which appeared on the screen", percentage of agree and strongly agree were reduced to 76.1%, and about 44.3% felt that they often met difficulties following computers' instruction when studying teaching material (question 12) It may be school computers of the elementary schools hosting the experiment lacked hard disks, and therefore limited so that during operation, even when the user instructions did not have any mistake, computers still would not work. Therefore students think although computers are easy to operate, messages appear on the screen which cannot be understood when computers just simply don't work, and this made them feel bad when doing exactly according to the instruction of the computers. From the answers that students gave, the software which this research adopted was accepted by most students.

As to opinions concerning CAI, 80.7% and 95.4% of students (question 13,14) expressed interest in CAI. Only 45.4% felt they didn't need the teacher for studying (question 15), and 93.2% (question 16) affirmed the teachers' importance when using CAI. In addition, 75% felt if they could study with other classmates, effects will be even better (question 17).

In respect to emotional feeling, students mostly like to study with computers (question 18), and didn't feel nervous when using computers (question 20). Most students would like to use CAI, and are happy to recommend it to others (question 19, 21). However, those students who used CAI already also expressed that study effects would be better if it could be used with other mediums (question 22).

As has been related above, after students accepted the CAI instruction, they all had a good appraisal of instructional software and CAI.

IV. Conclusions And Suggestions

1. Conclusions

From the results and disccussions of research we come to the conclusions listed below:

(1) Main effects of experimental treatment and field dependence of students' mathematics achievement had no significant difference, but experimental treatment and field dependence had an interaction with students' mathematics achievement. Field dependent students were more suitable for CAI coursew; field independent students were more suitable for traditional instruction.

(2) The main effects of experimental treatment and locus of control on students' mathematics achievement displayed no significant difference, and interaction between the two also was not found.

(3) After the experiment, mathematics achieve-

Table 3-13. The Analysis of Covariance Summary of Experimental Treatment on Computer Attitude's Post-test Grades

Source	SS	DF	MS	F	Sig of F	Groups	Adjusted Mean
Covariance	4943.67	1	4943.67			Experimental	92.63
Between groups (Experimental Treatment)	1004.79	1	1004.79	15.48	.000	Control	87.50
Within groups	11096.50	171	64.89				

Table 3-14. Results for Opinions of Students in Experimental Group about CAI

Teaching Software		Strongly disagree	disagree	no opinion	agree	Strongly agree
1. I can understand very clearly what I will learn from the explanation on the computer.	f	0	2	11	29	46
	p	0.0	2.3	12.5	33.0	52.3
2. Content explanation of CAI goes from easy to difficult and also in good order.	f	0	3	8	37	40
	p	0.0	3.4	9.1	42.0	45.5
3. I think the examples on computer can help me study	f	0	2	1	32	53
	p	0.0	2.3	1.1	36.4	60.2
4. Computer can point out where I make mistakes	f	1	3	8	19	57
	p	1.1	3.4	9.1	21.6	64.8
5. Computer can tell me whether the answers are correct or not immediately after I answere the questions.	f	1	2	4	22	59
	p	1.1	2.3	4.5	25.0	67.0
6. I can operate the computer for studying conveniently.	f	1	1	4	37	45
	p	1.1	1.1	4.5	42.0	51.1
8. After I answer the questions on the computer, the way the computer responds is very interesting.	f	0	5	4	26	53
	p	0.0	5.7	4.5	29.5	60.2
9. I think the content design of CAI is very attractive, it makes me keep thiking all the time.	f	1	8	5	33	41
	p	1.1	9.1	5.7	37.5	46.6
10. The specific representation format of the computer will intensify my impression of teaching material.	f	0	1	9	38	40
	p	0.0	1.1	10.2	43.2	45.5
11. I understand all the meaning of content which appeared on the screen.	f	1	9	11	42	25
	p	1.1	10.2	12.5	47.7	28.4
12. When studying teaching material, I do just as the computer instructs, and often meet difficulty.	f	12	21	16	25	14
	p	13.6	23.9	18.2	28.4	15.9
Computer Assisted Instruction (CAI)						
13. Learning through the computer, I feel the time flies fast.	f	3	5	9	32	39
	p	3.4	5.7	10.2	36.4	44.3
14. When I think I'll go tho the computer room for the next class, I feel very happy.	f	0	1	3	26	58
	p	0.0	1.1	3.4	29.5	65.9
15. In a computer class, I can study without a teacher.	p	17.0	27.3	10.2	22.7	22.7
16. When studying, if I sometimes can get help from teacher it will make me study better.	f	0	1	5	25	37
	p	0.0	1.1	5.7	28.4	64.8
17. I think if 2 or 3 classmates can study CAI together, I will study better.	f	6	10	6	29	37
	p	6.8	11.4	6.8	33.0	42.0
18. I like to study teaching material of the textbooks by using computer.	f	0	1	8	36	43
	p	0.0	1.1	9.1	40.9	48.9
19. If I have a chance in the future, I'd like to use computers to study some teaching material	f	0	0	3	27	58
	p	0.0	0.0	3.4	30.7	65.9
20. I don't fell nervous when I study with a computer.	f	0	7	3	38	50
	p	0.0	8.0	3.4	31.8	56.8
21. I'd like to recommend CAI to other classmates.	f	2	1	7	38	40
	p	2.3	1.1	8.0	43.2	45.5
22. If computers can go together with a TV screen and equipment of radio and tape recorder, I think it would be more helpful for me.	f	3	1	5	21	58
	p	3.4	1.1	5.7	23.9	65.9

f: Figure of people
p: Percentage

ment of students in CAI group and tradition instruction group had no significant difference.

(4) After the experiment, the mathematics attitude of students in CAI group and traditional instuction group had no significant difference.

(5) After the experiment, the computer attitude of students in CAI group and traditional instruction group showed significant difference, and CAI group was better than traditional instruction group.

(6) After accepting CAI instruction, students in CAI group held a positive attitude toward CAI.

2. Suggestions

In this section, suggestions for educational authorities, schools, and teachers and for further research in the future in accordance with findings and conclusions related above are respectively submitted.

(1) For Educational Authorities

A. Guiding the direction of course software development
B. Listing the maintainence and repair expenses for computer equipment
C. Pushing the implementation of CAI
D. Projecting informational education for formal courses in curriculum
E. Implementing a system of information teacher licensing for elementary schools

(2) For Schools

A. Implementing CAI should take into consideration students' personalized characteristics
B. The students' characters should be considered when arranging classes
C. Implementing informational education should based be on students' interests
D. Implementing CAI should be accompanied with teachers' explanation

(3) For Teachers

A. Students' characteristics should be observed when practicing teaching

(4) For Future Study

A. Enhancing research samples
B. Lengthening research time
C. Comparing different computer modeling effects
D. Examining students' other aptitudes for CAI's effect
E. Examining experimental results from the qualitative view
F. Examining the interaction of CAI's manner of expression and students' characteristics

Reference

Caffarella, E. P. et.al. (1980). Factor affecting instructor/ student ratios for self-paced instruction. *Educational Technology*, 5-9.

Chen, C. H. (1988). *Computer-assisted instruction*. Taipei: UNALIS Corporation.(In Chinese)

Chou, K. F. (1985). The participation of activities influencing on the behavior adaption for the university students of internal and external control. *Educational Review*, **6**, 159-221.(In Chinese)

Clouser, R. A., & Hjelle, L. A. (1970). Relationship between locus of control and dogmatism. *Psychological Reports*, **26**, 1006.

Duby, P. B. & Giltrow, D. P., (1987). Predicting student withdraws in open learning courses. *Educational Technology*, 43-47.

Hamsher, J. H., Galler, A. & Rotter, J. B. (1986). Interpersonal trust, internal-external control, and the Warren Commission Report. *Journal of personality and social Psychology*, **9**, 210-215.

Hersch, P. D., & Scheibe, K. E. (1967). On the reliability and validity of internal-external control as a personality dimension. *Journal of Counsulting Psychology*, **31**, 609-614.

Huang, C. H. (1979). A study on the internal-external control of chinese school pupils. *Bulletin of Educational Psychology*, **12**, 1-14.(In Chinese)

Li, C. P. (1983). Computer-assisted instruction. *Science Monthly*, *14*(8), 592-595.(In Chinese)

Li, M. Y. (1983). *The relationship between gender,grade, mathematics attitude and mathematics achievement*. Unpublished Master Thesis, National Chengchi University. (In Chinese)

Kapadia, M. V. (1987). *The relationship between cognitive styles and achievement under computer-based instruction and traditional instruction*. Unpublished Doctoral Dissertation, Memphis State University.

Messick, S. (1976). Personality consistencies in cognition and creativity. In S. Messick (Ed.), *Individuality in learning*. San Francisco:Jossey-Bass, Inc., Publishers. 4-22.

Phars, E. J. (1965). Internal-external control as a determinant of amount of social influence exerted. *Journal of Personality and Social Psychology*, **2**, 642-647.

Rotter, T. B. (1966). generalized expectancies for internal versus external control of reinforcement. *Psychological Monographs*, **80**(1), 1-27.

Seeman, M. (1963). Alienation and social learning in a reformatory. *American Journal of Sociology*, **69**, 270-289.

Straits, B. C., & Sechrest, L. (1963). Futher support of some findings about characteristics of smokers and nonsmokers. *Journal of Consulting Psychology*, **27**, 282.

Tin, C. F. (1987). *The influence of student's field dependence and teacher's instruction strategy onto student cognition and affection learning achievement*. Unpublished Master Thesis, National Taiwan Normal University.(In Chinese)

Witkin, H. D. et. l. (1977). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, **47**(1), 1-64.

Witkin, H. D., & Goodenough, D. R. (1981). *Cognitive styles*. New York:International University Press, Inc.

Wu, Y. Y. (1987). Individual differences in cognitive factors. *Educational Review*, **7**, 51-98. (In Chinese)

CAI對不同場地獨立性及制握信念的國小學生數學能力之影響

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摘　要

本研究以臺南縣一所國小五年級四個班級學生共174名爲研究樣本，隨機抽取二個班級的學生共88名爲實驗組，接受電腦輔助教學；二個班級的學生共86名爲控制組，接受傳統式教學，以比較利用電腦進行課後輔導的電腦輔助教學與接受利用評量及講解的方式進行課後輔導的傳統學對不同場地獨立性及制握信念的國小兒童之數學成就的影響，並期了解學生在接受不同實驗處理後，數學態度及電腦態度的差異情形及國小學生是否願意採用CAI來進行學習。

研究結果顯示場地獨立性和實驗處理之主要效果均未達顯著水準，但二者有交互作用，場地依賴型學生較適合電腦輔助教學，場地獨立型學生則適合傳統式教學。而制握信念和實驗處理之主要效果、交互作用則均未達顯著水準。此外，實驗組與控制組學生在數學態度上的差異亦未達顯著水準。但實驗組學生的電腦態度顯著優於控制組學生的電腦態度。實驗結束後，實驗組的學生對電腦輔助教學多持正向、積極的態度。

本研究並針對教育行政當局、學校、教師及未來進一步的研究分別提出建議，以期達成因材施教的目標。

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An Instructional Design for Greenhouse Effect STS Activity

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ABSTRACT

This paper is about an instructional design of a "Greenhouse Effect" STS activity for normal university chemistry sophomores, involving problem-centered, role-playing, cooperative learning. The roles played were consumers, manufacturers, environment protection administrators, bureau of forestry staff, and scientists.

The instructional strategies were designed based on the levels of learning synthesized by the author using instructional media to scaffold student activities. The student activities included small group learning (with collecting and analyzing information, small group discussion), class-sharing (with brain storming, role playing, debating), and proposing solutions, etc.

The assessment methods used were McDaniel's method for levels of open-ended thinking, paper-pencil tests for knowledge, and degree of participation for scoring the students' performance.

Here is strong positive correlations in learning achievements, expressed by percentage consistencies. These discerning consistencies are between: (a) degree of participation and paper-pencil test (85%); (b) degree of participation and level of thinking (80%); (c) paper-pencil test and level of thinking (80%); and (d) degree of participation, paper-pencil test, and level of thinking (75%).

This study shows the instructional design of the STS activities was successful. The results are summarized as follows.

(1) The STS activities kept the interest of the students throughout to a high degree.
(2) Students learned from participating in the STS unit activities to highly value the STS movement.
(3) STS activity development through scaffolded instruction altered students' science learning attitude to meet constructivist perspective and thus become able to design good STS activities.
(4) From these experiences the students concluded that good STS activities should solicit curiosity, promote discussion, use their own methods in making decisions and solving problems, and be extendible.
(5) Problem-centered, cooperative learning promoted students to construct high-order thinking, knowledge, skills, and views pertinent to the greenhouse effect issues in the real life.
(6) Students highly recommended that teacher training institutions should provide a formal course on STS activities.
(7) This action research supports the view that learning should be situated. Teachers must

learn from acting in authentic contexts if they are to become good teachers.

(8) The learning and assessment designed for the greenhouse effect STS activities are useful in other areas of science education.

Key words: greenhouse effect, problem-centered cooperative learning, role playing

I. Introduction

The science-technology-society (STS) movement is an educational reform designed to promote the citizens' science literacy in a technologically dominated society. The National Science Teachers Association (NSTA) in the USA has defined STS as the teaching and learning of science in the context of human experience. Many persons regard STS learning as constructive learning (Yager, 1993). From the constructivist perspective, knowledge is not passively received but actively built up by the learner. The teacher's role is to provide stimulating and motivational experiences through negotiation, acting as a guide in the building of personalized schema (Wheatley, 1991). To achieve the goal of STS, Waks (1992) designed an organizing framework that helps identify, select, organize, and sequence learning experiences to promote responsible citizenship in this technologically dominated society. The phases of learning cycles are: Phase 1, self understanding; Phase 2, study and reflections; Phase 3, decision making; and Phase 4, responsible action. Marzano (1992) proposed dimensions of learning that can improve the quality of learning on an issue related task. They are: Dimension 1, positive attitude and perceptions about learning; Dimension 2, acquiring and integrating knowledge; Dimension 3, extending and refining knowledge; Dimension 4, using knowledge meaningfully; and Dimension 5, productive habit of mind. Citizens acting on environmental issues possess four characteristics, namely: (a) issue awareness; (b) knowledgeable about how to resolve the issues; (c) able to act on issues; and (d) of certain personality and attitude that make them act (Sia, Hungerford, Tomera, 1986; Hines, Hungerford, Tomera, 1987; Rubba, 1991). Rosenshine and Meister (1992) pointed out that scaffolds not only are useful for teaching well-structured skills, but also provide the support students need to tackle higher-level thinking strategies. *Scaffolds are supports provided by the teacher or other students to help students fill the gap between their current ability and the required ability needed for the intended goal.*

II. Purpose of This Study

STS learning is distinctly different from the types of learning in the traditional science classroom. It was found that scaffolds are necessary for the first time STS learners (Wang, 1994). The purpose of this paper is to report a way of scaffolding, which gradually decreases as the STS activity progresses and the learners become more independent in STS learning.

III. Methods

Action research was used to find out if the instructional design is able to promote students' views, skills, and knowledge on the topic.

This study stands on the following beliefs:

(a) The best way for the students of a teacher training university to understand the STS approach is to experience it themselves as the learners.

(b) Deeply and strongly influenced by the traditional education, the students need scaffolding at the beginning of STS learning.

(c) Higher level cognitive skills, knowledge, beliefs, values, and world views which are needed in the real life can be developed from problem-centered STS unit activity.

(d) Favorable conditions for holistic learning exist when a person is faced with a task for which no known procedure is available.

(e) Cooperative small group learning would give a rich environment for enhancement, forcing them to reconstruct knowledge and skills of higher levels.

In the process they examined, confronted inconsistencies in, promoted open-ended thinking on, and constructed knowledge, skills, and views pertinent to the greenhouse effect.

1. Subject

The subjects of this study were 20 sophomores at Department of Chemistry, National Taiwan Normal University (NTNU).

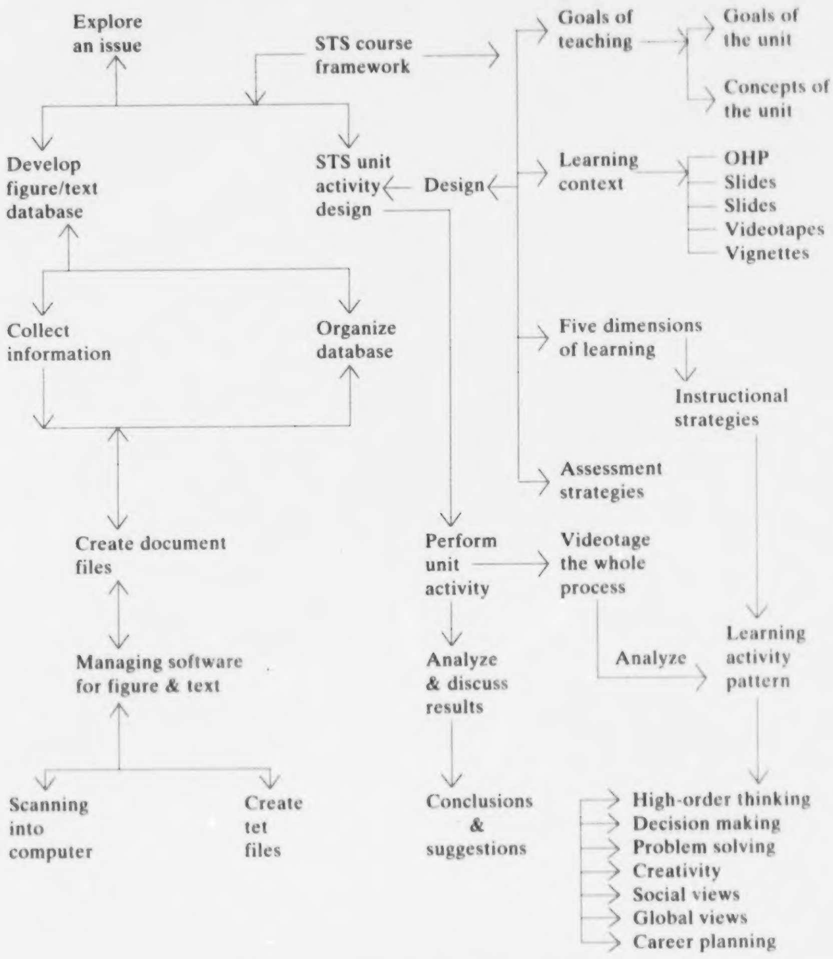
Explore an issue
STS course framework
Goals of teaching
Goals of the unit
Concepts of the unit
Develop figure/text database
STS unit activity design
Design
Learning context
OHP
Slides
Slides
Videotapes
Vignettes
Collect information
Organize database
Five dimensions of learning
Instructional strategies
Assessment strategies
Create document files
Perform unit activity
Videotage the whole process
Managing software for figure & text
Analyze & discuss results
Analyze
Learning activity pattern
Scanning into computer
Create tet files
Conclusions & suggestions
High-order thinking
Decision making
Problem solving
Creativity
Social views
Global views
Career planning

Figure 1. Procedure for developing STS unit activity

2. Developing "Greenhouse Effect" Units

The researcher developed the units in the following sequences (cf . Figure 1).

(a) reviewing problems with traditional views of science and science teaching;
(b) reviewing instructional and assessment strategies;
(c) selecting "Greenhouse Effect" as an STS topic to be developed;
(d) collecting information and developing relevant data bases;
(e) developing a prototype unit consist of unit goal, chemistry concepts; scenarios and vignettes with paradoxes, challenging questions, student activity, instructional strategies, assessment strategies;
(f) having the students perform STS learning activities which were videotaped;
(g) revising the developed unit.

3. Dimensions of Learning

Wang (1994) synthesized a set of five learning levels based on the works of Waks (1992), Marzano (1992), Sia et al. (1986), and Hines et al. (1991): Dimension 1, awareness of issues; Dimension 2, understanding; Dimension 3, decision making; Dimension 4, responsible action; and Dimension 5, STS literate personality. They were used to improve quality of STS teaching and learning.

4. Instructional media

The instructional media consisted of three scenarios and STS vignettes related to the topic "Greenhouse Effect," was developed to motivate and maintain students' interest in the topic. Scenario One was about the greenhouse effects caused by constant equilibrium concentration of carbon dioxide due to the balance between photosynthesis of plants and respiration of animals and plants in the nature. Scenario Two showed forests being devastated. Scenario Three pictured atmospheric air being polluted by the exhaust fumes from vehicles. STS vignettes consisted of a short illustrative story, challenging questions, and paradoxes. These all related to the "Greenhouse Effect." One example of the questions is: What sources of energy should we use without polluting the air?"

5. Instructional Strategies

Instructional strategies using problem-centered cooperative learning consist of (1) small group learning (a) collecting data and information, (b) analyzing data and information, and (c) small group discussion; (2) class-sharing (a) brain storming; (b) role playing as consumers, manufacturers, environment protection administrators, bureau of forestry personnel, and scientists (Figure 2); and (c) debating, with which to achieve deep thinking on the issue, make decisions, and propose solution for social problems. The strategies were to encourage students to pursue information processing approach emphasizing the ways situational information is perceived, selected, organized, and interpreted.

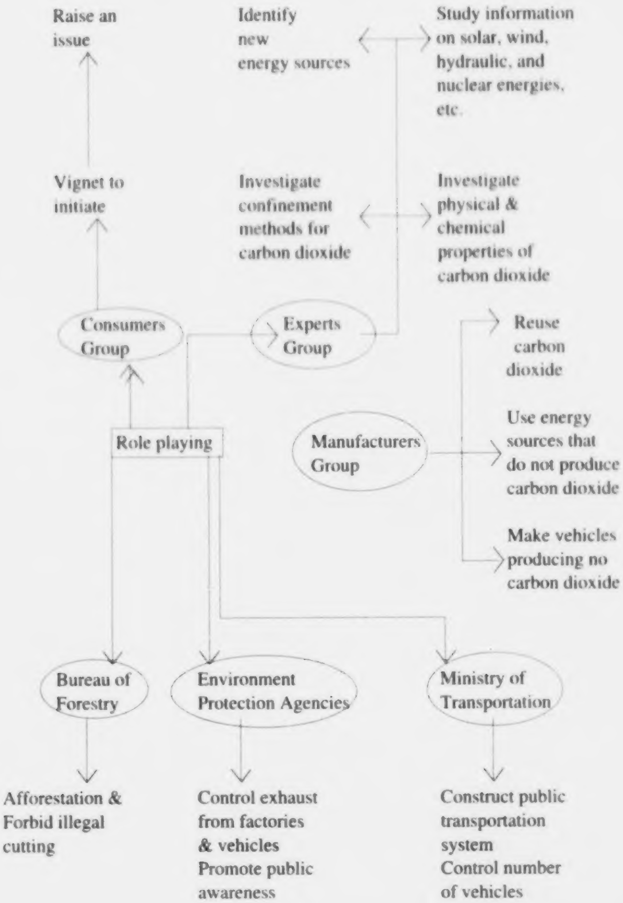
Raise an issue
Identify new energy sources
Study information on solar, wind, hydraulic, and nuclear energies, etc.
Vignet to initiate
Investigate confinement methods for carbon dioxide
Investigate physical & chemical properties of carbon dioxide
Consumers Group
Experts Group
Reuse carbon dioxide
Role playing
Manufacturers Group
Use energy sources that do not produce carbon dioxide
Make vehicles producing no carbon dioxide
Bureau of Forestry
Environment Protection Agencies
Ministry of Transportation
Afforestation & Forbid illegal cutting
Control exhaust from factories & vehicles Promote public awareness
Construct public transportation system Control number of vehicles

Figure 2. Role playing directed Greenhouse Effect STS activities

The learning dimensions were used as the dynamic framework to sequence the learning activities. Students are motivated to identify important issues and the related tasks. Then they were encouraged to identify the declarative and procedural knowledge needed to complete the tasks. They were further guided to identify the extending and refining activities needed to complete the tasks.

6. Assessment Strategies

(1) Scoring Method for the Open-ended Thinking on the Topic

The teachers' levels of cognitive complexity in the open-ended thinking on the STS issues were scored by the McDaniel's 5-point scale measurement. The test examples and the rating in the book (McDaniel and Lawrence, 1990) were used for interrater reliability (Wang & Tsai, 1994). Each of the five levels is defined as follows.

"Level 1 (1 point): Unilateral Descriptions. The student (i) simplifies the situation, (ii) focuses on one idea or argument, (iii) brings in no new information, meanings, or perspectives, (iv) makes good/bad, either/or assertions, (v) appeals to authority or simple rules rather than supporting ideas, and (vi) repeats or paraphrases information presented.

Level 2 (2 points): Simplistic Alternatives. The student (i) identifies simple and obvious conflicts without pursuing or analyzing, (ii) develops a position by dismissing or ignoring one alternative and supporting the other with assertions, and (iii) does not make deeper assessment of the situation.

Level 3 (3 points): Emergent Complexity. The student (i) identifies more than one possible explanation or perspective, (ii) establishes and preserves complexity, (iii) introduces new elements, and (iv) supports position through comparisons and causal statements.

Level 4 (4 points): Broad Interpretation. The student (i) uses broad ideas to help define and interpret the situation, (ii) manipulate ideas within the perspective established, (iii) has a clearly recognizable explanatory theme, and (iv) integrates ideas into "subassemblies," each supporting a component of the explanation.

Level 5 (5 points): Integrated Analysis. The student (i) restructures or reconceptualizes the situation and approaches the problem from a new point of view, (ii) constructs a network of cause and effect relationships, (iii) integrates and extrapolates ideas, (iv) arrives at new interpretations by analogy, application of principles, generaliza-

Table 1. The greenhouse effect issues: degree of particiption, paper-pencil test score, first and second tests for levels of thinking

Student No.	Gender	Group No.	Frequency of comment	Degree of %	paper-pencil test score	Assessment for levels of thinking	
						first	second
1	m	1	6	96	94	3	4
2	m	1	0	70	80	3	3
3	m	1	1	73	79	2	5
4	m	1	3	85	83	2	5
5	f	2	1	80	79	2	4
6	m	2	2	82	85	3	4
7	m	2	2	88	89	2	5
8	m	2	6	95	96	3	5
9	f	3	2	90	90	2	5
10	f	3	5	93	97	3	5
11	f	3	5	95	98	2	5
12	f	3	5	93	96	3	5
13	m	4	2	85	83	2	5
14	m	4	1	80	90	2	5
15	m	4	2	82	85	3	4
16	m	4	1	73	77	2	4
17	m	5	1	76	80	3	3
18	m	5	2	81	87	3	4
19	f	5	3	86	88	3	4
20	f	5	0	80	77	2	4

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tions, and world knowledge, and (v) constructs an organizing framework, links connections, and predicts consequences."

McDaniel's levels 1 and 2 were combined into the lower level in Table 2, because the learners' responses were mostly descriptions of the situation. Levels 3 and 4 were combined into the higher level, because the learners were able to explain how parts of the situation were interconnected (levels 3 and 4), their responses being noticeably analytic (levels 4).

(2) Assessment of Degree of Participation

Degree of participation (DP) is assessed considering the following three factors: information collection (IC) (30%), frequency of comment (FC) (40%), and quality of comment (QC) (30%). Quintessential students' performance in (a) contributing ideas or identifying problems; (b) challenging ideas by taking different perspectives; and (c) contributing in reaching consensus or proposing solutions, each student was scored 0 to 100 for each factor.

$$\text{DP of a student} = IC\times0.3+FC\times0.4+QC\times0.3$$

(3) Paper-pencil Test

Paper-pencil tests consisted of 40% multiple choice items and 60% open-ended test items. The multiple choice items were intended to assess whether the students could correlate the acquired scientific knowledge with the life; the open-ended items requesting concise answers were intended to assess the abilities as shown in Appendix 1.

7. Scaffolding

The students constructed STS literacy through activities under the researcher's scaffolded instruction. The different scaffolds used are as follows: (1) elements of STS literacy; (2) scenarios and vignettes with paradoxes and challenging questions; (3) support from peer students in the form of cooperative learning; (4) questions used to elicit constructive learning to achieve the learning goals and dimensions; and (5) assessments of the instructors and the peers. Scaffoldings were provided only when necessary, more in the beginning and fading slowly to build students' confidence in their abilities in constructivist learning.

8. Instructional and Assessment Procedures

The activity proceeded as follows.

First step (class-sharing and the first test for open-ended thinking): The three scenarios were presented to the students to scaffold their open-ended thinking. This was to encourage students to propose their own views on the issue. This is a brain-storming activity to motivate interest and promote the issue awareness. They were instructed to take time to (a) reflect on what they had heard and seen and (b) describe and explain their thoughts as completely. Participant responses ranged in length from half to one and one half pages, hand written. The responses were collected, copied, and scored. Then a paper-pencil test was conducted.

Second step (small group learning): Students were encouraged to form four groups on their choices, collect, organize, and discuss information on greenhouse effects to promote understanding on the issue.

Third step (class sharing): The students discussed on carbon dioxide, its chemical properties, applications, positive and negative effects on the human life. The positive aspects brought up were its diverse uses in soft drinks, baking soda, dry ice and other items. The negative aspects brought up were mainly greenhouse effect related issues. This activity encourage students to extend and refine knowledge.

Fourth step (class sharing): Students engaged in role playing and debating to solve social issues using science and technological methods. The roles were consumers, scientists, manufacturers, EPA personnel, and forestry bureau people. They were given the questions: The problem is that petroleum will be exhausted within 50 years and coal within 500 years. What should we do about energy resources? These activities were to introduce the students into deeper, open-ended thinking. This encourages imagination and creativity leading to blue prints of appropriate strategies of solution. Solar energy and alternative energy sources were brought up for discussion. Brain storming and peer learning expanded their knowledge to domains other than chemistry. They further discussed about their social duty and responsibility, establishing social as well as world views.

Fifth step (the second test and the paper-pencil test): The written responses in the first step were returned to them. They were then asked to use descriptive statements or STS maps to reflect their open-ended thinking on the issue (the second test). Then a paper-pencil test was conducted.

IV. Results and Discussion

The students were introduced to the STS activities on the topic. Of the 20 students 13 were males and 7 females. They were in five small learning groups. The results of assessing learning achievement in the greenhouse effect STS activities are summarized below.

1. Results of assessing levels of thinking

The students were encouraged to write down as much as possible what they had heard, seen, or thought about the greenhouse effect, so that their overall views and extents of understanding could be assessed. Their levels of cognitive complexity in open-ended thinking were scored with McDaniel's five-point scale (Table 1). The assessments on open-ended thinking revealed the levels of thinking, problem solving, creativity, and personal, social, and global values/ethics. The comparison of their writings between the first and the second tests revealed the changes in view points and abilities as the result of the activities. Such changes in a sample student, shown in Appendix 2, suggested that the activities helped students (a) link the topic with other knowledge within a discipline, with other disciplines, and with social and global problems; (b) understand the overall structural relationships, as revealed in the second test, among the elements in the topic; (c) understand the relationships between the already known (as demonstrated in the first test) and the presently learned elements; and (d) apply the process skills (such as induction, deduction, analysis and so on) already possessed to a new topic to find out similarities and differences, analyze, support, and elaborate in this new situation (the greenhouse issue). With McDaniel's measurement thus, the STS activities were found effective.

The results of the first and the second tests using open-ended test items were compared in Table 2. McDaniel's levels 1 and 2 were combined into the lower level, because the learners' responses to the test items were mostly description of the situation. Levels 3 and 4 were combined into the higher level, because the learners were able to explain how parts of the situation were interconnected (levels 3 and 4), their responses being noticeably analytic and integrated (levels 4). After the STS activity, initially lower levels of thinking rose to higher levels, regardless of genders.

The level increments revealed in the second test (Table 3) show that the instructional design promoted open-ended thinking and learning on the STS topic in the real life. Percentages of students rising from lower to higher levels of thinking were 35% (from level 2 to level 5, up three levels), 25% (from level 3 to level 4, up one level), 15% (from level 2 to level 4, up two levels), and 15% (from level 3 to level 5, up two levels). The remaining 10% were initially at level 3 and stayed there.

2. Assessment on degree of participation (DP)

During the STS activities, the students commented and discussed and these were recorded. Table 4 shows that the average frequency of comment was 2.5 for the class, 2.2 for the males, and 3.0 for the females. The average DP was 84 for the class, 81.7 for the males, and 88.1 for the females. The females surpassed the males, reflecting the females' were more enthusiastic with higher degree of participation in the STS activity.

Table 2. The greenhous effect issues: paper-pencil test score, first and second assessments for levels of thinking, percentage improvement

Category	Paper-pencil test %	Levels of thinking assessment				Low to High levels percentage improvement
		first assessment		second assessment		
		Low level	High level	Low level	High level	
		Numbers of students				
class	86.8	10	10	0	20	100
males average	85.2	6	7	0	13	100
females average	89.3	4	3	0	7	100

Table 3. The greenhouse effect issues: improvement in level of thinking

Level change	Males	Females	Class	Degrees of promotion, levels	Percentage
Level 2 to 3	0	0	0	1	0
Level 2 to 4	1	2	3	2	15
Level 2 to 5	5	2	7	3	35
Level 3 to 3	2	0	2	0	10
Level 3 to 4	4	1	5	1	25
Level 3 to 5	1	2	3	2	15

3. Paper-pencil tests

Table 4 shows that the average scores in paper-pencil test conducted at the end of the STS activities were 86.8 (class), 85.2 (males), and 89.3 (females). The females again surpassed the males. The class average score in the paper-pencil test (86.8) indicates that the STS activities are valuable in cultivating these abilities.

4. There are strong positive correlations expressed by percentage consistencies between: degree of participation and paper-pencil test (85%). Other areas of comparison were: degree of participation and level of thinking (80%); paper-pencil test and level of thinking (80%); and degree of participation, paper-pencil test, and level of thinking (75%). These demonstrate satis factory learning achievements (Table 5).

These data show that after participating in the STS activities, with the aid of scaffolds, almost all students advanced to higher levels of thinking and being able to comment on the STS issues. These comments show they have gained deeper understanding, problem solving ability, creativity, and appropriate social values. The advancement of learning performance can also be observed from the written test and the open-ended thinking assessments.

5. About role playing

During the role playing in the STS activities,

Table 4. The greenhouse effect issues: degree of participation, paper-pencil test scores

Category	Average frequency of comments	Average degree of participation	Paper-pencil test scores
Class	2.5	84.0	86.8
Males	2.2	81.7	85.2
Females	3.0	88.1	89.3
Group 1	2.5	81.0	84.0
Group 2	2.8	85.3	87.3
Group 3	4.3	92.8	95.3
Group 4	1.5	80.0	83.8
Group 5	1.5	80.8	83.0

Table 5. The greenhouse effect isues: positive correlations in learning achievement

Positive correlation between or among		Percent corelation
degree of participation	& paper-pencil test	85
degree of participation	& levels of thinking	80
paper-pencil test	& levels of thinking	80
degree of participation, paper-pencil test, levels of thinking	&	75

the students discussed over the merits, the shortcomings, and the solutions in the class sharing. The merits were:

(1) Brain storming facilitated
(2) Issue awareness aroused
(3) Many questions found
(4) Multiple perspectives opened out
(5) Relative positions assumable

The shortcomings were:

(1) Role playing restricted thinking
(2) Role players sticked too much to the roles assigned
(3) Some were unfamiliar with the roles assigned.
(4) Merely by role playing, questions could not be thoroughly discussed to find the answers.

The possible solutions for the shortcomings were:

(1) Adapt also other activity style such as debating.
(2) Keep or exchange roles.
(3) Volunteer roles other than the assigned.
(4) All members should engage in serious brain storming and discussion to obtain solutions without regard to the roles assigned.
(5) Switch from role playing to debating for more complicated problems.

In the class sharing discussion they found that the following steps must be taken to determine how the role-playing should take place.

(1) The students should form several role-groups.
(2) All students should find questions in the issue and pick up a tentative topic for the activity.
(3) Each role-group should take up the questions pertinent to the role; other questions may be added if necessary.
(4) Each role-group should discuss and design the procedures of STS activities for the topic in which all students will participate to solve and answer the questions.
(5) All roles exchange written reports on questions and activity procedures.
(6) All students should participate in discussing about the appropriateness of the questions and the procedures of the activities designed by each role group. The role playing STS activity they find most appropriate is accepted.

In this way, everyone will have the feeling that he or she has produced the role-playing STS activity.

This finding of shortcomings, solutions, and merits is in line with the constructivist view that learning grows out of own experiences in authentic contexts. Thus, unlike the explain-practice paradigm, the problem centered activity gave a rich environment in which the students not only construct knowledge, skills, and views related to the topic, but also find the types of STS activities they should use. This means that they have constructed their pedagogical content knowledge.

Conclusion

This study shows the instructional design of the STS activities was successful. The results are summarized as follows.

(1) The STS activities kept the students in high degree of interest throughout.
(2) Students learned from acting in authentic contexts. Having participated in the STS unit activities they highly valued the STS movement.
(3) STS activity development through scaffolded instruction altered students' science learning attitudes. This will help them to meet constructivist perspectives and thus become able to design good STS activities.
(4) From these experiences the students concluded that good STS activities should attract curiosity, promote discussion, use their methods in making decisions and solving problems, and be extendible.
(5) Problem centered, cooperative learning promoted students to construct high order thinking, knowledge, skills, and views pertinent to the greenhouse effect issues in real life.
(6) Students highly recommended that teacher training institions should provide a formal course on STS activities.
(7) This action research supports the view that learning is situated. Teachers must learn from acting in authentic contexts if they are to become good teachers.
(8) The design of learning/assessment using STS activities can be useful in reforming science education.

Acknowledgments

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Appendix 1

Open-ended Items in the Paper-pencil Test

No.	Item	Ability assessed
1.	Assuming the earth has no atmosphere surrounding it for protection, predict: (1) What would the day and the night temperatures be, and why? (2) How would the mankind and other living things be affected?	To analyze, predict, investigate
2.	Assuming the mankind continues to increase the concentrations of of carbon dioxide and other gases in the troposphere so that surface temperature keeps rising, how would the earth be adversely affected?	To criticize, judge, think, predict
3.	Imagine that you were a scientist or a government agent, propose at least two projects that would reduce the greenhouse effect.	To create, solve problem

Appendix 2
Changes in open-ended thinking of a student as an example

The student's response in the first test: Too much carbon dioxide in the atmosphere leads to (i) poor heat dissipation; (ii) violent changes in the global climate; (iii) the polar ice caps melting due to rising temperature resulting in rising of sea level; (iv) loss of fresh water; (v) abnormal climate; and (vi) frequent flood and drought. On the other hand, carbon dioxide is important as it can be absorbed by plants and used in the photosynthesis supporting life.

The student's response in the second test: The sunlight reaches the earth surface and the longer light waves are reflected back to outer space. The atmosphere absorbs parts of the light energy thereby preventing total loss of energy to space. The earth surface maintains at certain temperatures, not so cold or not so warm. This is the greenhouse effect. In absorbing energy, carbon dioxide plays a very important role; without it the life on the earth would become extinct. With civilization rapidly advancing, the amount of carbon dioxide increases dramatically, severely affecting the whole biological environment and the climate. Development of new energy sources and environmental preservation are the important tasks that the politicians and the scientists must seriously consider to find balanced answers. These efforts need the abilities of analysis and investigation.

The government agents emphasize economical development and social harmony while the scientists stress the ecological preservation. This creates differences that are hard to overcome. Ironically enough, too often the key policy makers are science illiterate and the operating agents are even worse. Therefore, the policy makers must be science literate and the agents must consist of professional scientists if the social and environmental problems are to be solved. These situations require decision making ability.

The tremendous increase in carbon dioxide and the continuous escalation of the greenhouse effect are due to the vast consumption of the fossil fuels and the extensive destruction of forests, which are the consequences of the human activities. To eliminate such undesirable situations the following two points must be considered.

(1) To decrease formation of carbon dioxide
  (a) Develop new energy sources such as solar energy and nuclear energy, to replace the fossil fuels.
  (b) Build public transportation systems to decrease the number of individual vehicles.
  (c) Develop production of electric vehicles.
  (d) Promote planting of forests and forbid illegal destruction of forests.
(2) To decrease the amount of carbon dioxide in the atmosphere
  (a) Cultivate bacteria or algae that will fixate carbon dioxide.
  (b) Store carbon dioxide in deep seas. (Carbon dioxide under high pressures and low temperatures is heavier than the sea water and will sink. Its surface being frost like, not diffusible, therefore liquid hydrogen carbonate injected down to deep sea hollows would stay there. Over a long time it will form deep sea mud containing calcium carbonate - a fantasy but nevertheless a demonstration of creativity!) The human economic activities should never cease and carbon dioxide will continue to increase before new countering strategies emerge. More professional researches are needed to solve the problem along the line mentioned above; of course, energy saving and resource recycling must be strongly advocated. (A demonstration of learned problem solving skills!) The greenhouse effect continues to escalate, resulting in disas-

trous destruction of the ecological equilibrium and influencing the entire earth.

References

Hines, J., Hungerford, H. & Tamir, A. (1987). Analysis and synthesis and of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education*, **18**(2), 1-8.

Marzano, R. J. (1992). *Different Kind of Classroom: Teaching with Dimensions of Learning*. Alexandria, VA: Association for Supervision and Curriculum Development.

McDaniel, E. & Lawrence, C. (1990). *Levels of cognitive complexity, An approach to the measurement of thinking*. New York: Springer Verlag.

Rosenshine, B. & Meister, C.(1992). The use of scaffolds for teaching high-level cognitive strategies. *Educational Leadership, April*, 26-33.

Rubba, P. A. (1991). Integrating STS into school science and teacher education: beyond awareness. *Theory into Practice*, **30**(4), 303-308.

Sia, A., Hungerford, H. & Tomera, A. (1986). Selected predictors of responsible environmental behavior: An analysis. *Journal of Environmental Education*, **17**(2), 31-40.

Waks, L. J. (1992). The Responsibility Spiral: A Curriculum Framework for STS Education. *Theory into Practice*, **30**(1), 13-19.

Wang, C. H. (1994). *A teachers' enhancement project in Taiwan*. Presented at National Science Teachers Association National Convention, Anaheim, California, March 30-April 2.

Wang, C. H. & Tsai, H. H.(1994). Promoting open-ended thinking on the STS topic:"Detergent." *Proceedings of the NSC-Part D, Vol. 3, No. 1*, 37-47.

Wheatley, G. H. (1991). Constructivist perspectives on science and mathematics learning. *Science Education*, *75*(1), 9-21.

Yager, R. E. & Roy, R. (1993). STS: Most pervasive and most radical of reform approaches to science education. In R. E. Yager (Ed.), *The Science, Technology, Society Movement, Vol. 7, pp. 7-13 of What Research Says to the Science Teachers*. Washington, D. C., National Science Teachers Association.

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溫室效應STS活動之教學設計

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摘　要

本研究設計大學生之溫室效應STS活動之教學策略；包括問題中心，角色扮演，合作學習。扮演的角色是消費者，廠商，環保人士，山林管理者和科學家。教學策略根據筆者規劃之學習層次當做鷹架，使用教學媒體帶動學生活動。學生活動包含小組學習（收集及分析資訊，小組討論），班級共享（腦力激盪，角色扮演，辯論）和提出解決問題之方案。學生的學習成就是由開放性思考（MacDaniel方法），知識（紙筆測驗）和參與度評量。各項評量結果間有高度的正相關：參與度與紙筆測驗成績間的正相關爲85％；參與度與思考階層間的正相關爲80％；參與度，紙筆測驗成績和思考階層之三者間正相關爲75％。從此研究結果得知此STS活動之教學設計是相當有效，而得到下列結論。

(1) 在活動過程中，學生都能保持高度的興趣。
(2) 學生從參與STS活動學習而認同STS取向的科學教育之重要性。
(3) 透過鷹架教學，學生在發展STS活動過程中，改變自己的科學學習態度去迎合建構學習觀點，而設計出好的STS活動。
(4) 從這些經驗，學生得知好的STS活動須能引起好奇心，促進討論，以自己的方法做抉擇和解決問題並需進一步的探討。
(5) 問題中心的合作學習，促進學生在與人生有關的溫室效應論題上，建構高階層思考，知識，技能和觀點。
(6) 學生建議師資培育機構須提供STS活動之正式課程。
(7) 此行動研究支持情境中學習之觀點。教師須從實際情況中學習始能稱職。
(8) 本人認爲溫室效應STS活動之學習與評量設計，對科學教育其他的領域有用。

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A Case Study on the Teaching Behavior of Novice Physical Science Teachers in Secondary School†

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ABSTRACT

Five novice physical science teachers from the Physics Department of X Normal University were selected as subjects of this study. Data was collected in three phases: the first phase occurred during the midterm of the first semester, the second phase during the final term of the first semester and the third during the midterm of the second semester. Methods of data collection in each phase consist of in-depth interviews includings a structured interview and an unstructured interview, classroom observations with tape recordings, and an investigation of students' perceptions of teaching. All the raw data was validated by triangulation and analyzed step by step involving the scientific methods of classification, induction, synthesis, and deduction. The study's general discoveries were made during the first step of analysis, while major assertions were made after further analysis of the general discoveries. Finally, conclusions were drawn from a synthesis of learning psychology, cognitive theory, and epistemology. This study revealed the following facts:

(1) The selected novice teachers believe in objectivism (including both realistivism and empiricism), and tend to teach their students by following the text exactly and doing the experiments as if they were cooking from a recipe.
(2) They seem to share such teaching strategies as giving oral explanations, outlining contents on the blackboard, directing students' learning via asking convergence questions or problem solving, controlling classroom order, repeating important concepts shortly after students answer questions, doing experiments in a recipe style, controlling lab order, and looking after each group's experiments.
(3) Their knowledge of teaching strategies is not sufficient.
(4) Their knowledge of lab teaching strategies is not sufficient.
(5) Their knowledge of individualized instruction and individualized teaching strategies is not sufficient.
(6) Their knowledge of constructivism and constructivist teaching strategies is not sufficient.
(7) Their knowledge of interaction and interactive teaching strategies is not sufficient.

Key words: teaching behavior, teaching belief, objectivism, constructivism.

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I. Introduction

The fundamental purpose of a normal university in the Republic of China is to educate qualified teachers. A science major student has to take four years of science major courses (such as Physics, Chemistry, Mathematics, English, etc.), as well as educational courses (such as Psychology, Learning Theories, etc.), before he can become a qualified teacher. Only after passing and completing all the requirements, will he be sent to begin his fifth year teaching practice, the novice teacher training. If he passes this training, he will receive his diploma and a high school teaching certificate.

The goal of the training in the fifth year is to provide novice teachers chances to link educational theories to real teaching situations, there by constructing their own teaching methods (which correspond to their personalities and suit the needs of this era). This teaching training is vital in that it influences not only the growth of the teaching capabilities ofthe novice teachers, but also the success or failure of upgrading the quality of science education in this country.

Chiang (1993, 19941, 1994b) listed a number of variables that influence teachers' teaching quality, such as personalities, professional knowledge, teaching beliefs, instructional skills, social environment of schools, etc.. What influences affect the novice science teachers? There are very few studies on these influences. In this study, we will apply the methods of in-deep interviews, tape-recordings, and collected student perceptions to gather effective data to analyze the following research questions.

1. Research Questions and Objectives

Our study will deal with whether or not graduates from the Physics Department of X Normal University possess sufficient knowledge of pedagogy and teaching capabilities to teach physics in secondary schools. We will try to answer the following research questions that have been designed for this study:

Question 1: What kinds of teaching knowledge have novice teachers learned?

Question 2: What kinds of teaching knowledge do they lack ?

Question 3: Will novice teachers' conception of science knowledge influence their teaching behavior?

2. Terminology

Several proper terminologies often used in the study are defined as following:

(1) Skillful Performance with time-serial change
Refers to the condition in which the novice teacher has become more and more skillful in the application of his teaching strategies because of the longer duration and frequent use of those strategies.

(2) Improving Performance with Time-serial Change
Refers to increasing frequency of application of teaching strategies because of the longer duration of use of those strategies.

(3) Decreasing Performance with Time-serial Change
Refers to decreasing frequency of application of teaching strategies because of the longer duration of use of those strategies.

(4) Teaching Belief
A basic teaching concept derived from the teacher's evaluation of his own attitude toward the related teaching pedagogy with reference to his own pedagogical knowledge, experiences, social viewpoint or emotion.

(5) Objectivism
A belief that scientific knowledge is objective, that is, there is absolute truth in nature. By truth is meant that the scientific knowledge discovered is compatible with reality.

(6) Constructivism
A belief that there is no absolute truth in nature. In other words, reality is subjective. Many scientific laws, theories and points of view do not exist in the real world but are invented by man's wisdom.

3. Limitations of the Study

(1) Because the qualitative study was time-consuming, only five physical science teachers were chosen as subjects of this study.

(2) Because the qualitative study included field observations and interviews, the subjects were limited to teachers around Kaohsiung City, Kaohsiung County and Pingtong County.

(3) The subjects were further limited to graduates from the Physical Science Department of X Normal University with the view that they could

work reliably with the researcher.

(4) Due to the limited number of subjects, there are no accessive inferences made in this study.

II. Literature Review

This review includes Part I which deals with the meaning and characteristics of belief, and Part II which deals with teaching behavior and teaching beliefs.

1. The Meaning and Characteristics of Belief

Scholars have different interpretations of the definition of belief. Lee (1933) considered beliefs as a guidance for external behavior and internal decisions, having various contents and being faithfully kept by individuals. Somewhat related to the idea in constructivism that knowledge is in-born, although beliefs may change, it may only be with difficulty. Beliefs are partially discernable, partially potential and sometime even undetectable to the individuals. Therefore, he pointed out, to prove the existence of beliefs, we need ample direct and indirect data.

Cornett (1990) asserted that beliefs and practical theories come from an individual's previous living and teaching experiences. These experiences shape his teaching behavior.

Tobin (1992) regarded beliefs as planning patterns of knowledge existing in the individual that drive him toward a certain goal and affect his external activities.

Tuan (1991) pointed out that beliefs may guide in-service teachers' individual actions. They are like a survival truth to the teachers that must be proven and supported by their own experiences.

Clark and Peterson (1986) and Tuan (1991) pointed out that many scholars used different terms for "beliefs", such as "teacher's personal perspective," "conceptual system," "principles of practice," "construct system," "practical knowledge," "implicit theories," and "orientation," etc.. Though somewhat different, these terms share one thing, that is, teacher's cognition and behavior are guided by their personal belief system, or value system. It is beliefs that make teachers' behavior more meaningful (Lee, 1993).

What then are the characteristics of beliefs? Nespor (1985) pointed out that beliefs have some of the important characteristics of "existential presumption", "alternative," and "affective and evaluative aspects". Of these characteristics he asserted that "affective and evaluative aspects" strongly affect the teachers' formulation of their individual idea of value, which further develops into their particular value system. This value system will evolve into a new belief by taking in other compatible systems. Beliefs and value system, therefore, are considered as a whole with two facets, and complement each other. Interacting with thinking, they are the headquarters for study and problem solving.

According to the characteristics mentioned above, beliefs could be classified as "existential presumption belief," "alternative belief," and "affective and evaluative belief". A brief definition for each will be explored in the following:

(1) Existential Presumption Belief

Abelson (1979) pointed out that the belief system usually involves some assumptions, which he termed assumption belive. For instance, if someone presumes that god exist, he would behave piously and wish that god's love could make his dream come true. Nespor (1985) revealed that teachers' presumptions of their students' characteristics, such as their ability, maturity, laziness, etc., would also mirror their teaching behaviors. For example, if teachers assume that their students' poor study performance results from their inability, then they would reduce the level of difficulty of the instructional content, assigning easier drills and homework. If, however, the poor performance is due to too abstract contents, then they may resort to more practical lab work as their instruction strategy.

(2) Expectant Beliefs

Nespor (1985) pointed out that a belief system includes expectations of certain things. For example, many teachers try very hard to set up special models of interaction with their students. The models might not be learned during their school years. For instance, a teacher might have been expecting a model of cordial and interesting teaching activities since his student years. Nevertheless the model might not belong to any teaching theories he had learned. Now that he is a real teacher, he doubtless would make his dreams come true when designing teaching activities.

(3) Affective and Evaluative Beliefs

The formation of affective and evaluative beliefs is mainly due to such factors as personal feelings, moods and subjective evaluations. Generally speaking, belief systems are affected more by affective and evaluative beliefs than by knowledge systems. Abelson (1979) and Nespor (1985) pointed out that teachers usually evaluate each part of curriculum contents according to their affective and evaluative system. Meanwhile they will reflect their evaluation in teaching behavior. Thus affective and evaluative beliefs affect teachers' involvement in teaching activities.

What variables do teachers get their beliefs from? Referring to the schema chart of teachers' practical knowledge vs. their teaching behaviors developed by Duffee & Aikenhead (1992), this study constructed Figure 1 to clarify the relationship between belief system and teachers' teaching behavior (Chiang, 1993, 1994a). This figure indicates that a teacher's belief system is mainly influenced by the teacher's past experiences and his teaching environment. These past experiences include the teacher's educational experiences, such as pedagogy of cognitive education, scientific knowledge, educational theories and strategies (Aikenhead, 1984; Duffee & Ailenhead, 1992; Lantz & Kass, 1987), and the teacher's experiences from living and teaching. The teaching environment includes school administrative style, curriculum structure, software and hardware equipment, and the interaction among colleagues, students and the local social environment. (Duffee & Aikenhead, 1992).

Synthesizing the various theories of teacher's

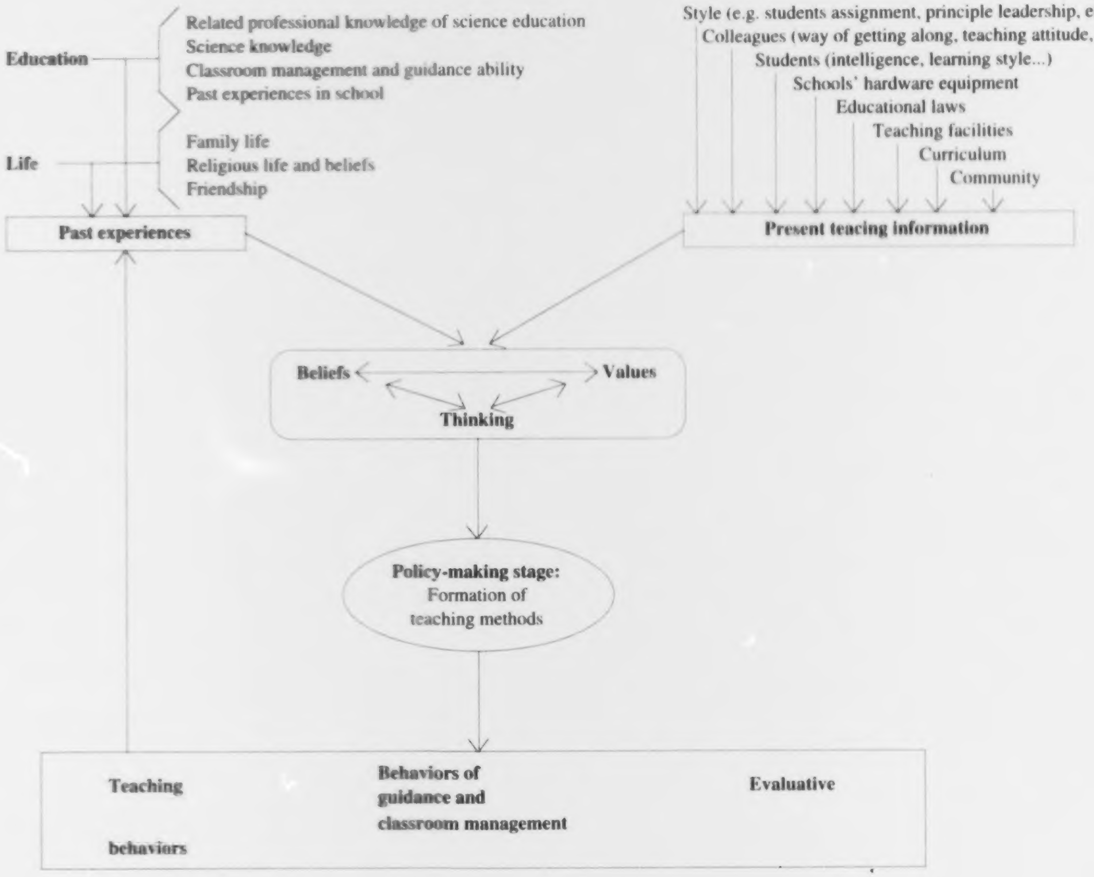
Education
Related professional knowledge of science education
Science knowledge
Classroom management and guidance ability
Past experiences in school
Life
Family life
Religious life and beliefs
Friendship
Past experiences
Style (e.g. students assignment, principle leadership, etc.)
Colleagues (way of getting along, teaching attitude, ...)
Students (intelligence, learning style...)
Schools' hardware equipment
Educational laws
Teaching facilities
Curriculum
Community
Present teacing information
Beliefs
Values
Thinking
Policy-making stage:
Formation of
teaching methods
Teaching
behaviors
Behaviors of
guidance and
classroom management
Evaluative

Fig. 1. Flow chart of teaching behavior and teacher's belief system

belief mentioned above, we obtain the following conclusions: Teacher's teaching belief is the sum of the elemental teaching concepts and attitudes based on a teacher's own knowledge, logic, experience, social viewpoint, and emotion, etc. Teaching beliefs construct teachers' belief system which will direct their teaching strategies and behaviors.

2. Teaching Behavior and Teaching Beliefs

From what has been mentioned above we know that teachers' teaching behavior, class management, and evaluation are all deeply influenced by their belief system. Theoretically, we can analyze the interaction between teacher behavior and belief system via the effective data from in-depth interviews and field observations. However, some studies showed that the variables influencing belief systems are too complicated and nonlinear, and that they sometimes give belief and behavior more of a nonlinear relation. Nevertheless, a teacher's teaching behavior controlled by his belief system will never change. Here we will offer some examples of actual research to explain the interaction between teachers' belief systems (or value systems) and their teaching behavior, class management, or evaluation:

Cornett (1990) applied the qualitative research method to a 20-hourclass observation and formal and informal interviews in order to investigate the beliefs of a science teacher who taught gifted and ordinary students. He also analyzed how these beliefs influenced her behavior in the classroom. Results of this study showed that the teacher possessed seven important teaching beliefs that had affected her teaching behavior. The interaction between them will be discussed as follows:

(1) Believing in the Importance of Visual Learning

The case teacher believed "to see is to believe". For example, to illustrate the process of geothermal energy pushing through the earth's crust, she would kneel down and ask two of his students to hold their hands above her head. Then she pushed straight through the students' hands. In this way she gave a visual demonstration of the process of how geothermal energy pushes through the surface of the earth.

(2) Believing in the Importance of Talking in the Student's Terms

The case teacher illustrated scientific concepts by resorting to the students' experiences and languages. For instance, to illustrate the concept of sinking ocean plates she had two students push each other to simulate it. At the same time, she would explain the ocean plate concept by using students' language. .

(3) Believing in the Importance of Interesting Science Learning Activities

The case teacher believed that making science learning fun could stimulate students'participation in the teaching activities. For instance, she took her students outside the classroom to gather soil samples in order to show them different kinds of soils. This process of learning helped stimulate students' interest in joining in her teaching activities.

(4) Believing in the Importance of Higher Levels of Learning

The case teacher provided her students many problem-solving activities, trying to help them relate to the concepts that they had learned. She also asked them higher levels of problems to stimulate their thinking abilities. As for the gifted class, she frequently asked more divergence questions.

(5) Believing in the Importance of Discipline in Class

The case teacher demanded that her students to behave themselves in class. She walked around the classroom to maintain classroom order.

(6) Believing in the Importance of Reinforcement

The case teacher considered it important for her students to learn through a variety of learning strategies. For instance, during class hour she would have her students read their textbook first before using a projector, pictures or peer discussion to illustrate the related contents and concepts in their reading..

(7) Believing in the Importance of Saving Students' Dignity

When they had made errors, students were usually given another chance to correct themselves instead of receiving immediate blame. Cornett regarded this as a case of influence upon the teacher's teaching strategies or teaching behavior from their own personal teaching beliefs.

Various similar cases are found in studies by Ching-ee Chang (1992), Hollon & Anderson (1987), Tuan (1991), Thompson (1984), Brickhouse (1989a, 1989b, 1990) and Tobin & Frase (1989). Synthesizing the related literature mentioned above, we knew that the same methodology and procedure could be applied to process the analysis in this study.

III. Methods

This study adopted the time-series method designed by Campbell and Stanley (1963) to collect the related qualitative and quantitative data in three phases. Figure 2. shows the folw chart of study design and related tasks which inclued quantitative and qualitative studies:

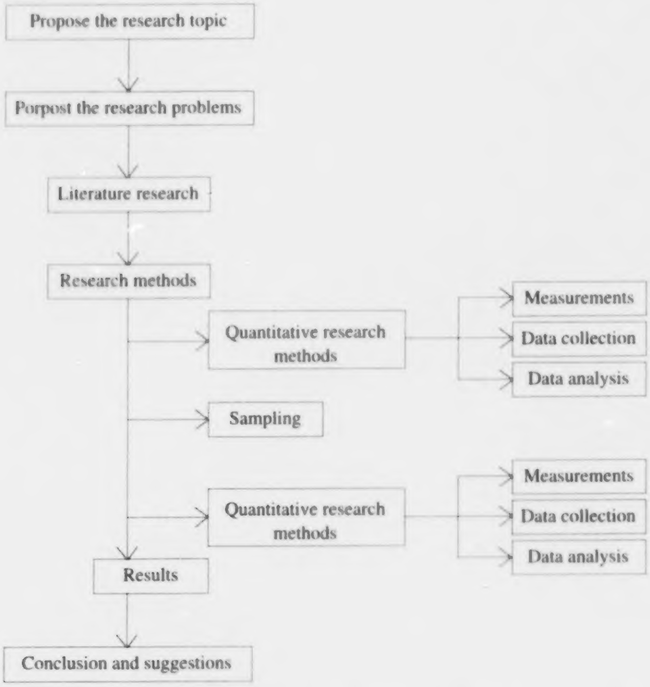
Propose the research topic
Porpost the research problems
Literature research
Research methods
Quantitative research methods
Measurements
Data collection
Data analysis
Sampling
Quantitative research methods
Measurements
Data collection
Data analysis
Results
Conclusion and suggestions

Fig. 2. Flow chart of study design and related tasks

1. Quantitative Study

There are two kinds of quantitative study. One consists of collecting students' perception data about their science teachers' teaching in order to estimate the reliability of video records taken in the classes; the other consists of collecting data during the three phases via video records, in-depth interviews, documents, etc., to analyze the time series change of teaching strategies used by the novice teachers. These changes were classified as skillful performance, improving performance, and decreasing performance with time series change. Following is a detailed description:

(1) Students' Evaluative Questionnaires About Their Science Teacher's Teaching

Questionnaires were developed by Chiang (1994). They include the 22 questions shown in Table 2. Question #1 through #18 are signed as Lkert Scale most agreeable, agreeable, no comment, disagreeable, and most disagreeable. The test-retest reliability was 0.77*** (***$P<0.001$). Data collection was processed in three phases as shown in Table 1.

The contents of questionnaires were recategorized according to teaching strategies following Table 2. The selected items were translated into numerical scores, such that the most agreeable item equaled a score of 5, the agreeable item equaled a score of 4, etc.. thereupon the data were analyzed via variance analysis.

(2) Materials That Were Video-Recorded in Class

Teaching activities data that were video-recorded in class are shown in Table 3, while those in the science lab are shown in Table 4. These data can be analyzed by T-Test or F-Test, and also by qualitative study.

2. Qualitative Study

The goal of the qualitative study is to investigate the values or beliefs that dominate the teaching behavior of novice teachers, especially viewpoints of science knowledge, educational ideals, and teaching ideals. To attain this goal, we need to collect sufficient effective data from various aspects, different environments and time series change through different methods of data collection, such as video recording, questionnaires of students' perceptions, and semistructured and unstructured in-depth interviews. In a word, the methods of qualitaative study are flexible and mobile in this research. Interviews of the study, data collection and data analysis are described in detail as follows:

Table 1. Phases of data collection and samples of students' evaluative questionnaires

Phases	Period of Collection	Samples of Students
Phase 1	From Oct. 7, 1993 to Nov. 4, 1993	Teacher A (3 classes): 129
		Teacher B (3 classes): 135
		Teacher C (3 classes): 137
		Teacher D (3 classes): 120
		Teacher E (4 classes): 180
Phases 2	From Dec. 16, 1993 to Jan. 20, 1994	Teacher A (3 classes): 123
		Teacher B (3 classes): 129
		Teacher C (3 classes): 137
		Teacher D (3 classes): 122
		Teacher E (4 classes): 174
Phases 3	From Dec. 11, 1994 to Apr. 20, 1994	Teacher A (3 classes): 122
		Teacher B (3 classes): 124
		Teacher C (3 classes): 129
		Teacher D (3 classes): 116
		Teacher E (4 classes): 176

(1) Interviews

Several semistructured and unstructured interviews given during the qualitative study were classified as following.

(A) Semistructured and unstructured interviews with school principals and supervisors from each case teacher's school at the beginning of the school year.

(B) Semisturctured interviews with case teachers abut their background information, including their childhood information, given at the beginning of school year.

(C) Three semistructured interviews concerning the change of case teacher's teaching behavior and teaching beliefs. The second and the third semistructured interviews are shown in Table 5.

(D) Two semistructured interviews with the science supervisor at the beginning of the first semester and at the midterm of the second semester.

(2) Data Analysis

The methods of categorizing, induction, deduction, synthesis, and triangulation were applied in the data analysis of this study. The following is the flow chart of data analysis:

VI. Results

The discussion of this study will focus on the following two aspects:

- The Time-Serial Change of Novice Teachers' Behavior in Class
- The Time-Serial Change of Novice Teachers' Behavior in the Lab

The related analysis is described as following:

1. The Time-Serial Change of Novice Teachers' Behavior in Class

The types of teaching behavior in class are defined in Table 6.

Following the definitions mention above, each novice teacher's teaching behavior will be discussed as follows:

(1) Teaching Behavior Before Class

The teaching behaviors of case novice teachers before class are generally defined in Table 7.

Table 2. Recategorizing "Students' Evaluative Questionnaire of Science Teaching"

Teaching Strategies	**Category of Students' Evaluative Questionnaire**
1. Using supportive graphs to explain or help students think and learn.	6. Our teacher is good at using supportive graphs to help our thinking.
2. Directing students to apply formulas or concepts to answer questions.	7. Our teacher is good at guiding us to say the formulas related to the lesson. 8. Our teacher is good at guiding us to aply the formulas to solve problems. 9. Our teacher will give similar or related explanatory questions after teaching a formula.
3. Using demonstrative experiments to help concrete think and learning	13. Our teacher often uses demonstrative experiments.
4. Using examples to give explanations	9. Our teacher will give similar or related explanatory questions after teaching a formula. 14. Our teacher often mentions the phenomena of daily life in discussions.
5. Using group learning or discussion.	16. Our teacher's teaching is often conducted through discussion. 17. Our teacher often allows us to discuss freely in the lab class.
6. Using homework.	1. I can do most of the homework given by my teacher.
7. Attracting students' attention in class.	5. Our teacher often allows us to discuss freely in the lab class.
Students' Perceptions	**Categories of Students' Evaluative Questionnaire**
1. Perception of teachers' style	3. Our teachers' teaching is very lively and interesting.
2. Perception of interest in science	4. The tesaching methods of our teacher can increase my preference for science class 15. I am very much interested in the demonstration experiments. 18. I am very much interested in science.
3. Perception of helping thinking ability.	2. Our teacher's is good at directing us to do exercises through our own thinking. 10. The examples given by our teacher can help us to think and ask questions.
4. Perception of helping learning (or understanding) science.	11. The demonstrations given by our teacher are very helpful to my learning. 12. The demonstration experiments given by our teacher are very helpful to my learning.
Other References and Materials.	19. Can I understand science teaching? ☐ most of them ☐ half of them ☐ some of them ☐ few of hem
	20. Can I understand science calculations? ☐ most of them ☐ half of them ☐ some of them ☐ little of them
	21. Can I understand science experiemtns? ☐ most of them ☐ half of them ☐ some of them ☐ few of them
	22. My science scores in the last monthly test? ☐ 100-80 ○ 79-60 ☐ 59-40 ☐ under 39

(Please refer to Table 3 for records of teaching activities.):

Before lecturing, teachers would attempt to make the classroom atmosphere suitable for learning. At first, they wouldn't do anything more than calling the roll or giving a lecture in order to keep the class in good order. Later they would try to stimulate learning motivation. Finally they began to teach..

From the point of view of learning psychology we know the objective of teaching behavior before class is to help students concentrate their attention and to arouse their curiosity and motivation to learn a new lesson. It also helps students recall what they have previous learned in order to link it with the new knowledge and thus enhance their learning effectiveness.

How did the five case novice teachers behave

Table 3. Records of Teaching Activities

Items	Y.	N. /H	F. /H	M.
Before Class				
1. Roll call				
2. Pre-lecture discipline in order to keep order				
3. Briefly explain the goal or points of a new lesson				
4. Stimulate learning motives by stories, news, special contents or experiments				
Materials Used in Class				
5. Standardized textbook				
6. Self-designed materials				
7. Supplementary calculation questions				
8. Tests by publishers				
General Strategies Used When Teaching				
9. Asking open-ended or convergence quetions				
10. Asking divergent questions				
11. Studetns answering questions in item 9				
12. Students doing item 11, but without satifying answers				
13. Students answering questions in item 10				
14. Students doing item 10, but with mistakes				
15. Teacher directs students' answering questions				
16. Waits during answering time (until students' have answered)				
17. Teacher outlines lesson on the blackboard				
18. Teaches asks students to take notes				
19. Teacher asks students to solve questions on blackboard				
20. Teacher asks each students to write down answers				
21. Teacher asks students to draw a line under important concepts				
22. Teacher asks students to discuss certain concepts or problems				
23. Using teaching aids (such as models, slides, video tapes, cassette tapes and graphs)				
24. Using simple demonstration experiments				
25. Arranging group study or discussion				
26. Walking around and directing students learning				
27. Asking students to recite contents after teachers				
28. Demandng some students recite contents				
29. Stopping teaching activity and giving discipline lecture				
Strageies of Reinforcement Used in Class				
30. Praising student's correct answers				
31. Criticizing student's errors with guidance				
32. Criticizing students]s errors with displeasure				
33. Guiding a student criticize another's answer				
34. Waiting for an answer and then reviewing important concepts of that quesion				
35. Conducting written test				
36. Practicing calculation problems				
37. Discussing answers on test sheet				
Before the End of Class				
38. Concluding important concepts				
39. Giving necessary homework				

Note: F.=Frequency of perfomrance; M.=Minute; H.=Hour; Y.=Yes; N.=No

before giving their lecture? And what were their time-serial changes? The following analysis will provide a true picture of the pre-class behavior of the five case novice teachers:

Teacher A

The analysis of the video records taken in classes during the three phases, the data from correspondence interviews, and the students' per-

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Table 4. Records of Teaching Activities

Items	Yes	No	Feq. /hour	Min. /hour
Before Class				
1. Calling the roll				
2. Pre-lecture discipline in order to keep order				
3. Recalling the flaws of the last experiment				
4. Explaining the goal of an experiment				
5. Safety reminder before the experiment				
6. Explaining the procedure of an xperiment				
Materials Used in Class				
7. Standardized textbook				
8. Self-designed instructional materials				
9. Partly self-designed instructional materials				
10. Guiding experiments in each group				
11. Looking around each group's experimental activities				
12. Stopping experimental activities and reminding of important issues				
13. Writing down experimental data or discoveries on blackboard				
14. Asking students to give experimental records				
15. Asking each group to talk about their experimental discoveries				
16. Asking students to ask about each other's discoveries				
17. Directing students to discuss each group's discoveries				
18. Discussing experimental errors				
Before the End of Class				
20. Summing up importand discoveries and concepts				
21. Request writing of experimental reports				
22. Suggesting improvements in experiment				
23. Inspecting each group's cleanup work				

Note: Frq.=Frequency of performance; Min.=Minute

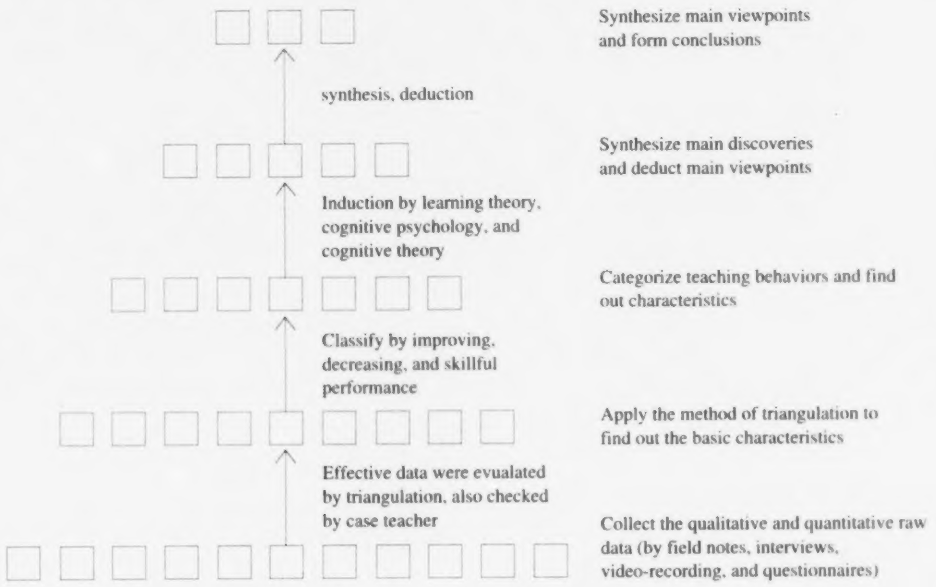
Synthesize main viewpoints and form conclusions
synthesis, deduction
Synthesize main discoveries and deduct main viewpoints
Induction by learning theory, cognitive psychology, and cognitive theory
Categorize teaching behaviors and find out characteristics
Classify by improving, decreasing, and skillful performance
Apply the method of triangulation to find out the basic characteristics
Effective data were evualated by triangulation, also checked by case teacher
Collect the qualitative and quantitative raw data (by field notes, interviews, video-recording, and questionnaires)

Fig. 3. Flow chart of data analysis

Table 5. Outlines of the Second, and the Third Phase Structured Interviews with Novice Teachers

1. From beginning teaching until now, have you changed any of your teaching goals or beliefs? On what items? and why?
2. From beginning teaching until now, have you taught science following the order, writing style and contents of textbooks? Or have you rewritten them in your own order, style and added some extra materials? Please explain why.
3. From beginning teaching until now, have you changed any methods of experimental teaching?
   The methods are defined as:
   (1) The way of preparing experimental materials
   (2) The way of controlling experimental time
   (3) The way of dividing experimental groups
   (4) The way of writing reports
   (5) The way of stating experimental discoveries
   (6) The way of discussing experimental discoveries
   (7) The way of maintaining lab safety or order
   (8) The way of rearranging lab
   (9) The way of determining experimental effectiveness
   Please explain changed items listed above. And the reasons?
4. From beginning teaching until now, have you changed any methods of your teaching? The methods are defined as:
   (1) Lecturing speed
   (2) Lecturing tone
   (3) Lecturing manner
   (4) Blackboard-writing style
   (5) The way of paying attention to students during lecturing
   (6) The way of handling students' noises
   (7) The way of handling sleepy students
   (8) The way of handling students' gossip and messages
   (9) Requesting note-taking
   (10) The habits of self-asking and self-answering
   (11) The way of encouraging students' questioning
   (12) The way of encouraging students' enjoyment of science
   (13) The way of encouraging students' questioning the bottom
   (14) The way of teaching abstract conceptions
   (15) The way of teaching abstract conceptions
   (16) The way of handling students' convergence questions
   (17) The way of encouraging studetns' discussion
   (18) The way of scoring students' notes
   (19) The way of discussing tests
   (20) The way of using tests
   (21) The way of using reference books
   (22) The way of controlling teaching schedule
   (23) The way of controlling learning atmosphere
   Please explain the changed items listed above. And the reasons?
5. From beginning teaching until now, have you changed your methods of experiment teaching?
   The methods are difeined as:
   (1) The way of preparing experiments
   (2) The way of preparing experimental materials
   (3) The way of handling the problem of students who can't see the experiments clearly
   (4) The way of handling important concepts in experiments
   (5) The way of directing students to use important experimental concepts
   Please explain the changed items listed above. And the reasons?
6. From beginning teaching until now, is it easier and easier for you to apply related science knowledge learned in university to explain or direct your science teaching or experimenting? Please describe your perception and the specifics of these problems.
7. From beginning teaching until now, has there been any help (on teaching or living) from the guidance group or guidance teachers of your school? For which items did you hope to get additional help or reinforcement? Please explain in detail.
8. From beginning teaching until now, has there been any help (on teaching or living) given by guidance professors of thephysics department of X university? For which items did you hope to get additional help or reinforcement? Please explain in detail.
9. From beginning teaching until now, have you changed anything concerning students' guidance or class management (such as cleanness contests, class order...), etc.? And the reasons?
10. From beginning teaching until now, have you changed any of your interpersonal relations, viewpoints of colleagues, or viewpoints about being a teacher? And the reasons?

Table 6. Types of Teaching Behavior in Class

1. teaching behavior before class
2. behaviorusing material
3. general behavior when taching
4. behavor using reinforcement strategies
5. teaching behavior before the end of class.

Table 7. Teaching Behaviors Generally Used before Class (Reference from Table 3)

1. calling the roll
2. Pre-lecture discipline in order to keep order
3. Briefly explaining the goal or points of a new lesson
4. Stimulating learning motives by stories, news, special contents or experiments

ception questionnaires showed that to attract students' attention and stimulate student motivation, teacher A always reviewed or discussed from lecture notes materials that she had given in the previous class before beginning a new lesson. In other words, the teaching behavior before class adopted by teacher A is similar to item #4 listed in Table 7. As a whole, we have observed that this behavior became better and better with time series change. The following is a discussion of teacher A's teaching behaviors:

Discovery A-1: Teacher A always used prior knowledge as content before teaching a new lesson. He then managed to attract his students and stimulate their motivation through discussion. He became more and more skillful as he gained more teaching experience. Teacher A's teaching behavior before class was "skillful performance" with time-serial change.

Teacher B

The same technique of analysis applied to teacher A was also applied to teacher B. We found that teacher B's behaviors before class were: calling the roll, listing the goals of the new lesson, and giving students learning motivation by demonstrations, or recalling students' previous knowledge or living experience. These behaviors were similar to the items #1, #3, and #4 listed in Table 7. We also discovered that teacher B became more skillful after gaining more teaching experiences. The following is a discussion of teacher B's teaching behaviors:

Discovery B-1: Before teaching, teacher B would call the roll to keep students quiet. He then immediately turned to the learning objectives of the new lesson to get them ready for it. He also gave a demonstration, or triggered students' past experiences to raise their learning motivation. His teaching behaviors became more and more skillful as he used them more. Therefore teacher B's teaching behavior before teaching is "skillful performance" with time-serial change.

Teacher C

In the case teacher C, we found that no matter whether in higher achievement classes or in average achievement classes, the class order was not very good. Students' noise always enraged teacher C who would then reproach them before beginning to teach. Teacher C always gave prelecture discipline before class which was similar to item #2 listed in Table 7. The following is a discussion of teacher C's teaching behaviors:

Discovery C-l: Teacher C did not try to trigger students' past experiences or raise their learning motivation before teaching. What he did was to blame students loudly and repeatedly. This kind of teaching behavior clearly showed no improvement with time-serial change.

Teacher D

In the case teacher D, we found his behaviors before class were quite similar to those of teacher C, such as making pre-lecture discipline as the item #2 listed in Table7. The following is a discussion of teacher D's teaching behaviors:

Discovery D-l: Teacher D's teaching behaviors before class were similar to those in discovery C-l. Though he attempted not to scold his students before teaching, he failed.

Teacher E

In the case teacher E we found he always called the roll before teaching. The following is a discovery of his teaching behavior:

Discovery E-1: Teacher E did not try to make his students recall past experiences or arouse their learning motivation before teaching. What he often did before lecturing was to call the roll. This kind of teaching behavior did not involve time-serial change.

Synthesizing the behaviors before teaching of the five case novice teachers, we found both teachers A and B employed the elementary theory of learning psychology to help their students use their prior knowledge and to arouse their learning motivation. Their teaching strategies became more skillful or improved when they gained more teaching experience. Thus inferences from our analysis offered the following points:

Point 1: The beginner teachers will become more and more skillful or improved in their teaching strategies if they used them frequently. This is called "skillful performance" or "improving performance" with time-serial change.

In this study only two case teachers' (teacher A and teacher B) teaching behaviors before teaching corresponded with the theory of learning psychology. By referring to the interview data again, we may make another point as follows:

Point 2: Beginner teachers from the Physics Department of X Normal University did not possess sufficient teaching knowledge and abilities to link their teaching behaviors to the real teaching situation.

(2) Behaviors Using Teaching Materials

Table 8. Materials Generally Used in Secondary School Science Teaching (Reference from Table 3)

1. Standard textbook
2. Self-designed materials
3. Supplementary calculation questions
4. Test sheets by publishers

In this study we define materials generally used in secondary school science teaching as follows:

In addition to standard science textbooks edited by the Ministry of Education of the Republic of China, which are supposed to be the sole materials generally used in secondary school, there are still many different editions designed either by the teachers themselves or by publishers. These science textbooks are used for supplementary calculation questions, or test sheets, for the purpose of preparing students for the High School Entrance Examination, or for different students' achievement tests, or sometime for the teachers' own teaching ideals. What are the behaviors of five case novice teachers with reference to the teaching materials? The following is a discussion:

Teacher A

The interview data, students' perception questionnaire and video recordings were taken in three phases. The data of the first phase indicated that teacher A adopted his self-designed materials in both higher achievement classes as well as in lower achievement classes. When asked for an explanation, teacher A admitted that he was influenced by a science teacher in his senior high who always rewrote textbooks for his students. After analyzing the structure of his teaching materials, we did not find that teacher A had any ideal about the concept of individualized education.

All data in the second phase indicated teacher A had already adopted standard textbooks for his lower achievement classes. In the third phase, the data revealed he even used reference books by other publishers instead of his own materials for higher achievement classes. Discovery A-2 describes the transition of materials used of teacher A in the three phases.

Discovery A-2: After teaching for some time, teacher A's ideals and enthusiasm in teaching dwindled but he became more practical. Getting more teaching experience, he shifted from using self-designed materials to standard textbooks, and then to reference books. We consider teacher A's behavior in adopting materials as "skillful performance" with time-serial change.

Teacher B

The sources of data are similar to those of Teacher A mentioned above. All data indicated teacher B only used textbooks as his teaching materials. Discovery B-2 as follows describes his teaching behavior during the three phrases in the analysis:

Discovery B-2: Teacher B used standard textbooks as the only teaching materials. Hence, there was no time-serial change in his teaching behavior.

Teacher C

The sources of data are similar to those of Teacher B mentioned above. All data indicated teacher C always used reference books by other publishers instead of the standard textbooks. The behavior of teacher C was described as follows:

Discovery C-2: Teacher C only uses reference books as the main teaching materials. Hence, there was no time-serial change in his teaching behavior.

Teacher D and Teacher E

The behaviors of teacher D and E were similar to those of teacher B. Hence Discovery D-2 and Discovery E-2 are similar to that of Discovery B-2. Our analysis of teaching materials showed that only one novice teacher ever designed his own materials. All the others merely adopted textbooks or reference books as teaching materials. From our analysis we can infer the following points:

Point 3: Novice teachers from the physics department of X Normal University place too much reliance on using standard science textbooks and reference books. They ignore the needs of individual students.

It is a fact that students have individual differences. How did these novice teachers handle these differences? The interview data indicates that they used materials from reference books to cram higher achievement students. As for the lower achievement students, they were often taught with less materials, or some of the contents were just skipped over. Of the five case novice teachers, no one ever seemed ever to care about the problems of individual need. Thus we can make the following point:

Point 4: Novice teachers from the Physics Department of X Normal University have very limited knowledge of designing individualized materials, evaluations, or teaching methods. They always resorted to standard textbooks or reference books for their primary teaching materials.

(3) General Teaching Behaviors During Teaching

In this study we define teaching behaviors generally used during teaching in Table 9.

What were the general teaching behaviors of the five case teachers during their teaching ? How was their performance? Our analysis showed that the following teaching strategies were used in different degrees by the five case teachers:

Table 9. Generally Used Teaching Behaviors During Teaching (Reference from Table 3)

1. Asking open-ended or divergence questions
2. Asking convergent questions
3. Students answering questions in item 1
4. Students doing item 3, but without satisfying answers
5. Students anwering questions in item 2
6. Students doing item 2, but with mistakes
7. Teacher directs students' answering questions
8. Waits answering time (until students' have finished answering)
9. Teacher outlines a lesson on the blackboard
10. Teaches asks students to take notes
11. Teacher asks students to solve questions on blackboard
12. Teacher asks each student to write down answers
13. Teacher asks students to underline important concepts
14. Teacher asks students to discuss certain concepts or problems
15. Using teaching aids (such as models, slides, video tapes, cassette tapes and graphs)
16. Using simple demonstration experiments
17. Arranging group study or discussion
18. Walking around and directing students learning
19. Asking students to recite contents after teachers
20. Demanding some students recite contents
21. Stopping teaching activities and giving discipline lecture

Teacher A

Discovery A-3: Teacher A seldom used strategies like group discussion or group study during his teaching. His teaching strategies therefore displays "decreasing performance" with time-serial change.

Discovery A-4: Teacher A seldom used demonstrations as a teaching strategy, which displays "decreasing performance" with time-serial change.

Discovery A-5: Teacher A often uses explanations as a teaching strategy, which displays "improving performance" with time-serial change.

Discovery A-6: Teacher A understands some methods of effective learning, which present "improving performance" with time-serial change. For instance, he would demand students to solve questions on the blackboard and to underline the important concepts in their textbooks, and to read the important concepts aloud in the class. He would also walk around to direct them in these teaching activities. All this shows that teacher A has realized the importance of students' problems in learning science.

Teahcer B

Discovery B-3: Though teacher B never adopts strategies like group discussion or group study, he often uses open-ended questions to lead his students in a short discussion. His teaching behavior presents "improving performance" with time serial change.

Discovery B-4: Teacher B once adopted a demonstration as a teaching strategy. However, it presents "decreasing performance" with time-serial change.

Discovery B-5: Teacher B often uses teaching strategies such as directing students' answers, making examples and drawing graphs for his interpretation ofthe science text. All these present "improving performance" with time-serial change.

Discovery B-6: Teacher B often uses convergent questions as a teaching strategy. This also presents "skillful performance" with time serial change.

Teacher C

Discovery C-3: Though teacher C never adopts strategies like group discussion or group study, he sometimes asks open-ended questions. He failed because of the poor answers of his students. Therefore his teaching behaviors present "decreasing performance" with time serial change.

Discovery C-4: Teacher C once used teaching strategies such as directing students' answers, using a simple demonstration and drawing graphs to help make his explanation clear. But all these present "decreasing performance" with time serial change.

Discovery C-5: Teacher C likes his students to solve questions on a piece of paper rather than on the blackboard. This forces students to think hard for the answers. This teaching behavior presents "improving performance" with time-serial change.

Discovery C-6: Teacher C often uses teaching strategies such as asking convergence questions, writing teaching contents on the blackboard, and demanding his students to read from their textbook. These teaching behaviors present "skillful performance" with time serial change.

Teacher D

Discovery D-3: The teaching strategies which teacher D often used are "improving performance' with time serial change, including asking convergence questions, outlining the teaching contents on the blackboard and giving examples to direct students' responses.

Duscivert D-4: The teaching strategies which teacher D often used and was "decreasing performance" with time-serial change include: Asking open-ended questions, drawing graphs for explanation, and using simple demonstrations. Since teacher D could not control students' participation and their order, his teaching was always behind schedule. He did not want to continue these strategies. Thus they present "decreasing performance" with time serial change.

Discovery D-5: Teaching strategies that teacher D never used include asking students to take notes, solve questions on the blackboard, write down answers, discuss certain concepts or problems, engage in group study or discussion, underline important concepts, or recite the teaching contents. Furthermore, he never walked around the classroom to direct students' learning, and never stopped his teaching to give special discipline to his students.

Teacher E

Discovery E-3: The teaching strategies which teacher E often used and was "improving performance" with time-serial change include: Explaining with examples, asking convergence questions, outlining the teaching contents on the blackboard and demanding students answer questions on a piece of paper.

Discovery E-4: The teaching strategies which teacher E always used that present "skillful performance" with time-serial change include: Walking around the classroom while reading teaching contents, stopping his lecture to give discipline to the class, demanding students underline the important concepts in textbooks, etc..

Discovery E-5: The teaching strategies which teacher E once used that present "decreasing performance" with time-serial change include: Using graphs or charts to help explanation, asking each group to discuss certain concepts or problems during reading, arranging group study or discussion, and using simple demonstrations.

By synthesizing the teaching features shown in the teaching behaviors of the five case teachers, we discover that some teaching strategies are never used, some are used but present "decreasing performance" with time-serial change, some are used at a later phase and present "improving performance" with time-serial change, and some are often used and present "skillful performance" with time serial change. Some of the common characteristics will be discussed as follows:

The teaching strategies that all five case teachers often used and present "improving performance" with time-serial changes include: Lecturing (such as graphing and presenting examples to help explanation), outlining subjects on the blackboard, directing students' learning (such as asking convergence questions and allowing students to solve problems themselves), and controlling class order.

The teaching strategies that all five case teachers never used or used once but present "decreasing performance" with time-serial change include: Asking open-ended questions, arranging group study or group discussion, asking students to discuss certain concepts or problems, and using simple demonstrations as teaching aid.

Synthesizing the philosophical viewpoints of the teaching strategies of case teachers,we reach to following conclusion:

Point 5: The five novice teachers basically do not think that students can construct their own scientific knowledge. Instead, they believe scientific knowledge consists of some existing conceptions, rules, principles or laws that can be learned only through teachers' instruction and students' frequent practice.

(4) Behaviors of Reinforcement Strategies During Teaching

In this study we define reinforce strategies that are often used in Table 10:

Table 10. Reinforcement Strategies Often Used during Teaching (Reference from Table 3)

Strategies of Reinforcement Used in Class

1. Praising student's correct answers
2. Criticizing student's errors with guidance
3. Criticizing student's errors with displeasure
4. Guiding a student to criticize another's answer
5. To wait for an answer and then review important concepts of the question
6. Conducting a paper test
7. Practicing calclation problems
8. Discussing test sheet answers

Before the End of the Class

9. Concluding important concepts
10. Giving necessary homework

Next we come to the question of the general reinforcement teaching strategies used often by the five case teachers during their teaching. What are they? How is their performance? By the same methods of analysis discussed previously, during the three phases we discovered that the reinforcement strategies variously used in class by the five case teachers are as follows:

Teacher A

Discovery A-7: Teacher A is not good at using a reinforcement strategy with an emotional feedback function.

Discovery A-8: Teacher A is not good at using the reinforcement strategy of summarizing the concepts that have been taught in the class.

Discovery A-9: Teacher A is not good at using the reinforcement strategy of evaluating critically differences in viewpoints between teachers and students as well as between students themselves.

Discovery A-10: Teacher A emphasized the reinforcement strategy of repeating testing, and it has "skillful performance" with time-serial change.

Discovery A-11: Teacher A used the reinforcement strategy of repeating practice to emphasize the importance of concept learning, and it has "improving performance" with time-serial change.

Teacher B

Discovery B-7: Teacher B also uses the reinforcement strategy of repeating practice to emphasize the importance of concept learning, and it has "improving performance" with time-serial change.

Discovery B-8: Teacher B emphasizes the importance of calculation learning, so he often asks students to do calculation problems.

Teacher C

Discovery C-7: Teacher C is not good at using reinforcement strategies. The only reinforcement strategy he used was praising.

Teacher D

Discovery D-6: Like teacher A, teacher D is not good at using a reinforcement strategy that has an emotional feedback function.

Discovery D-7: Teacher D uses the reinforcement strategy of repeating practice as teacher B did to emphasize the importance of concept learning, but it has "decreasing performance" with time-serial change.

Teacher E

Discovery E-6: As did teacher A, teacher E prefers to use a reinforcement strategy that has emotional feedback function such as praising or judging.

Discovery E-7: Teacher E prefers to use tests as a reinforcement strategy, and it has "skillful performance" with time-serial change.

Discovery E-8: Teacher E likes to use repeated explanation as the reinforcement teaching strategy to emphasize the importance of conception learning. It has "improving performance" with time-serial change.

Synthesizing the teaching behaviors of five case teachers in using reinforcement strategies, we discover that some reinforcement strategies listed in Table 10 are never used, some are once used but present "decreasing performance" with time-serial change, some present "improving performance" with time-serial change, and some present "skillful performance" with time-serial-change. Their common characteristics are inferred as the following:

The teaching strategies that all five case teachers have never used or once used and display "decreasing performance" with time-serial change include: evaluating a student's errors with guidance and guiding students to analyze critically the answer of another student. The philosophical viewpoints of these two reinforcement strategies aim at directing students to construct their own correct science concepts, as well as to develop their creativity. Thus we come to the following viewpoint:

Point 6: Novice teachers did not have enough knowledge about the theories of interactive learning.

Point 7: Novice teachers are poor in their knowledge of constructivism. That is why they give up the interactive learning strategy and emphasize the transmitted teaching strategies of objectivism.

Except C teacher whose reinforcement strategies can not be determined clearly, the reinforcement strategies commonly used by the other four case teachers, and showed "skillful performance" or "improving performance" with time-serial change, are: waiting for the answer and then reviewing important concepts of that question. Synthesizing the philosophical viewpoints of that reinforcement strategy, we discover its main goal is to emphasize the importance of conceptual learning. Thus we arrive at the following inference:

Point 8: Novice teachers strongly emphasize existing and formal science concepts.

Therefore they keep students doing frequently repeated learning.

2. The Time-Serial Change of Teaching Behaviors in Lab

In this study we classified the teaching behaviors in the lab in Table 11. Following are some of the discussions that we have made:

Table 11. Categories of Teaching Behaviors in Lab (Reference from Table 3)

1. Teaching behavior before experiments
2. Behavior using experimental materials
3. Teaching behavior during experiments
4. Teaching behavior before the end of experiments

(1) Teaching Behavior Before Experiments

Video data and the correspondence interview data taken during the three phases all indicated that only teacher A and C had done some lab teaching. The teaching behaviors often used before experiments is defined as in Table 12.

We may then ask the questions: What are the experimental teaching strategies often used by case teachers A and C? How is their performance? We can infer that the characteristics of teachers A and C using experimental materials are as follows:

Table 12. Teaching Behaviors before Experiment (Reference from Table 4)

1. calling the roll
2. Pre-lecture discipline in order to keep order
3. Reminder of the flaws of the last experiment
4. Explaning the goal of the experiment
5. Safety reminder before the experiment
6. Explaning the procedure of the experiment

Teacher A

During the first phase teacher A was very much concerned with the experimental and safety procedures and explained them very carefully before the experiment. Even during the experiment he showed his concern by using the method of adding or deducting points from the scores of each group to have them stay orderly and do the experiment seriously. He directed experiments for each group and inspected their situations. Although he asked each group to give him their experimental data, he did not discuss any of it. The situation during phase II was similar to that of phase I. In the third phase, in order to develop students' ability to operate experimental apparatus by themselves, he asked his students to read experimental materials, such as goals, procedures and safety, etc. by themselves. Of course they could ask their teacher to help them if they had problems.

According to the video recordings taken during the three phases, we did not find teacher A displaying any of the teaching behaviors listed in Table VI-7. Is this discovery true or not? Now we are going to look at it from the three interview data.

The interview data show that teacher A only allowed students in the higher achievement class to do experiments. He would explain the experimental goal (to prove the phenomena or laws in the textbook), remind them of safety and explain the procedure in class (not in the lab) before experiment. During experimenting he would not repeat those points. Students did the experiment as soon as they entered the lab, and he would inspect some groups. That was why the video recording did not present all of his teaching behaviors listed in Table VI-7 and we had to supply it from interview data.

From the data mentioned above we could infer the features of teacher A's lab teaching behaviors as follows:

Discovery A-12: Teacher A's detailed explanation of the goal before experiments shows that he tried to prove certain phenomena and laws, and hence there is no time-serial change.

Discovery A-13: Teacher A's detailed explanation of experimental procedures shows that he used a recipe method to teach experimental activities, and there is no time-serial change.

Discovery A-14: What teacher A did was to train his students how to operate experimental apparatus which basically consists of a skill ability, but not cognitive abilities such as observation or discovery ability. However, this teaching behavior presents "skillful performance" with time-serial change.

Teacher C

During the first phase teacher C wrote down the experimental procedures, objectives and the safety items on the blackboard and explained them to his students. He also directed each group separately and inspected their experiments. The second and third phases were similar to that of the first phase. According to the video data taken in the three phases as well as the corresponding interview data, we find the features of teacher C's lab teaching as follows:

Discovery C-8: Similar to discovery A-12.

Discovery C-9: Similar to discovery A-13.

(2) The Behavior of Using Experimental Teaching Materials

In this study we define the experimental instruction materials often used before experiments as in Table 13:

What were the instructional materials often used by teachers A and C? The features of teachers A and C's using experimental teaching materials are as following:

Teacher A

Table 13. Experimental Teaching Materials Defined in this Study (Reference from Table 4)

1. Standardized textbook
2. Self-designed instructional materials
3. Part of self-designd instructional materials

Discovery A-15: Teacher A used all standardized experimental teaching materials, which indicated no time-serial change.

Teacher C
Discovery C-10: Similar to discovery A-15

(3) Teaching Behaviors During Experimenting.

The experimental teaching behaviors are defined as in Table14:

Table 14. Experimenatl Teaching Behaviors Defined in this Study (Reference from Table 4)

1. Guide experiments in each grup
2. Inspecting each group's experimental activities
3. Stopping experimental activities and reminding of important issues
4. Writing down experimental data or discoveries on blackboard
5. Asking students to give experimental records
6. Asking each group to talk on their experimental discoveries
7. Asking student to ask about each other's discoveries
8. Directing students to discuss each group's discoveries
9. Discussing experimental errors
10. Creating ideas for new experimenta designs

Table 14 reveals that the features of teachers A and C's using experimental materials during the three phases are as following:

Teacher A
Discovery A-16: The experimental teaching goal of teacher A is to prove the theories or phenomena listed in the textbook.
Discovery A-17: Teacher A did not use any strategy of interactive learning in his experimental teaching.

Teacher C
Discovery C-11: Similar to discovery A-16.
Discovery C-12: Similar to discovery A-17.

(4) Teaching Behaviors Before the End of Experiments.

Teaching behaviors before the end of experiments are defined as in Table 15.

The features of teachers A and C's teaching behaviors before the end of experiments are as following:

Table 15. Experiment Teaching Behaviors before the End of Eexperiemtns (Reference from Table 4)

1. Summing up important discoveries and concepts
2. Asking students to write experimental reports
3. Reminding of the improvements in experiments
4. Looking around at each group's cleanup work

Teacher A
Discovery A-18: At the end of the experiment teacher A never did any further discussion or explanation besides trying to prove the theories and laws in the text-book.

Teacher C
Discovery C-13: Teacher C's behavior before the end of the experiment was similar to that in discovery A-18.

Of the five case teachers there were only two who wanted to do science experiments, and one did it only for higher achievement class. In sum, we can infer that

Point 9: For these two novice teachers it seemed that lab teaching was not necessary because they could do it on the blackboard (this is usually termed as "blackboard experiment" and has been very popular with other science teachers). This was why the other three teachers did not do lab teaching.

Point 10: Only few novice teachers from the Physics Department of X Normal University liked to do lab teaching. They formally used the recipe teaching strategy to teach experiments. Their main teaching goal was to prove certain phenomena, rules, laws or principles in the textbook in order to help students deepen their impressions of the scientific knowledge they had learned.

V. Conclusions and Suggestions

Our analysis of the teaching behaviors of five novice teachers from the Physics Department of X Normal University revealed 10 important points as mentioned above. What kind of conclusion can we drawn from these 10 viewpoints? Points 5, 7, 8, 9, and 10 clearly show that many teaching behaviors of the case teachers were influenced by their scientific professional knowledge. That is, their belief in objectivism (include realistivism and empiricism) affected the way that they taught physical science. Our analysis therefore leads us to the following conclusion and provides possible answers to **research question 3**.

Conclusion I: The case teachers from the Physics Department of X Normal University believe in objectivism (including realistivism and empiricism). Thus they tend to transmit knowledge in the lessons to their students while teaching but use a recipe strategy while instructing lab work .

As mentioned previously, knowledge about teaching skills or strategies that present "skillful performance" or "improving performance" with time-serial change can only be effective under the condition that the teachers already possess that knowledge and are willing to apply it in their teaching. How did the case teachers perform in this area?

Our analysis in the previous section showed that they did not have this knowledge. Two of them, however, always gave their students prelecture discipline, such as demanding quiet or scolding them before they began to teach, which presented skillful performance. Another two usually used different methods to motivate their students before teaching, which also presented improving performance with time-serial change.

With reference to point 3, we found that teaching behaviors using teaching materials were different among the five case teachers. One of them used reference books as the only teaching materials for his higher achievement classes, while the rest solely depended on standard textbooks.

As for "skillful performance" or "improving performance" of teaching strategies with time-serial change, we found that the teachers all shared such teaching strategies as: The strategy of explanation (such as using graphs or living examples to explain a point), outlining contents on the blackboard, directing students' learning (such as asking convergence questions or asking students to solve problems), and keeping the class orderly.

As to the reinforcement strategies used in teaching, we did not find that they had anything in common. Four of them, however, often used reinforcement strategies that presented "skillful performance" or "improving performance" with time-serial change. For example, they might explain important concepts again shortly after students gave correct answers.

The lab teaching strategies used by the two novice teachers with "skillful performance" with time-serial change were: recipe-style lab teaching, control of order in the lab, and looking around at each group's experiment.

In summary, we have reached the following conclusion and provide an answer for **research question 1**.

Conclusion 2: The teaching knowledge that the case teachers from the physics department of X Normal University have in common is: The teaching strategies of explanation, outlining, directing students' learning (such as by asking convergence questions or asking students to solve problems), controlling class order, explaining important concepts again shortly after students' answers, recipe-style lab teaching, controlling lab order, and looking around at each group's experiments.

Next, we come to another question. What conditions do teaching behaviors show in "decreasing performance" with time-serial change? In this study we consider the following two conditions:

The first condition is when the user (or teacher) is not familiar with the teaching skill and his teaching strategy does not show any effects. Therefore why his teaching behavior displays "decreasing performance" with time-serial change.

The second condition is when the user feels more and more uncomfortable with his teaching strategy. Taking the demonstration strategy as an example, some of the case teachers thought it a waste of time doing demonstrations because demonstrations are time-consuming and they had too much regular content to catch up with. That is why they were reluctant to use demonstrations in teaching. Since "blackboard experiments" are more effective, they replaced demonstrations as a teaching strategy.

How are we therefore to differentiate and classify the teaching strategies that show "decreasing performance" with time-serial change? Our analysis is based on interview data with the case teachers as well as the judgment of the writer who synthesized all information concerning teaching strategies.

Why would a teacher seldom apply a certain teaching strategy in his classroom? One answer could be that a teaching skill is unsuitable for his teaching environment. On the contrary, in this study we found that the reason is due to teachers' lack of basic knowledge of using these strategies, as mentioned in points 3, 4, and 6.

Synthesizing the information in points 2, 3, 4, 6, and 9, we can make the following conclusions and provide answers for **research question 2**:

Conclusion 3: The case teachers' knowledge of teaching strategies was not sufficient.

Conclusion 4: They did not have sufficient knowledge of lab teaching strategies because they lacked training in lab teaching theory and strategies.

Conclusion 5: They did not have sufficient knowledge of individualized instruction theories and strategies.

Conclusion 6: They did not have sufficient knowledge of constructivist theory and strategies.

Conclusion 7: They did not have sufficient knowledge of learning interaction theory and strategies.

According to the conclusions mentioned above, we make the following suggestion:

Suggestion: Due to the limitation of samples in this study, whether the seven conclusions we reached are universal or not is a question requiring of further research.

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References

Abelson, R. P. (1979). Differences between belief and knowledge systems, **Cognitive Science**, **3**, p. 355-366.

Aikenhead, G. S. (1984). Teacher decision making: The case of Prairie High. **Journal of Research in Science Teaching**, **21**(2): pp. 167-186.

Brickhouse, N. W. (1989a). Teachers' content knowledge about the nature of science and its relationship to classroom practice. (**ERIC Document Reproduction Service No. ED306133**)

Brickhouse, N. W.(1989b). The teaching of the philosophy of science in secondary classrooms: Case studies of teachers' personal theories. **International Journal of Science Education**, **11**(4), pp. 437-449.

Campbell, Donald T. ,& Stanley, Julian C. (1963). **Experimental and quasi-experimental designs for research**. Rand McNally College Publishing Company, Chicago.

Chang, Ching-ee (1992): A case study of senior science teachers in elementary schools. **Paper presented at Conference of Elementary School Science Education in 1992,** National Pintong Teachers' College. (in Chinese)

Chiang, Shing-ho (1993): A research program on mathematics & natural science teacher training: (III) A correlation study on difficulties of science teaching and teachers' beliefs in secondary school in Taiwan. Research report for NSC 82-01 11-S-017- 007. Printed by **Graduate Institute of Science Education** , NKNU. (in Chinese)

Chiang, Shing-ho (1994a): A study on secondary school science teachers' beliefs and their intrinsic character in Taiwan. **Kaohsiung Normal University Journal, 5** , 59-184. (in Chinese)

Chiang, Shing-ho (1994b): A study of physical science teachers' beliefs in secondary schools. Research report for NSC 83-01 11-S-017-012. Printed by Graduate Institute of Science Education, NKNU. (in Chinese)

Clark, C. M. & Peterson, P. L. (1986). Teachers' thought processes. In Wittrock, M. C. (Ed.), **Handbook of Research on Teaching** (p.253-296).

Cornett, J. W.; Yeotis, C. & Terwilliger, L. (1990). Teacher personal beginner theories and their influence upon teacher curricular and instructional actions: A case study of a secondary science teacher. **Science Education**, **74**(5), pp. 517-529.

Duffee L. & Aikenhead (1992). Curriculum change, student evaluation, and teacher beginner knowledge. **Science Education**, **76**(5), pp. 493-506.

Hollon, R. E. & Anderson, C. W. (1987). Teachers' beliefs about students' learning processes in science: Self-reinforcing beliefs system. Paper presented at the annual meeting of the American Educational Research Association, Washington, D. C.

Lantz, O. & Kass, H. (1987). Chemistry teachers' functional paradigms. *Science Education*, **71**(1), pp. 117-134.

Lee, Hui (1993): A case study of constructive approach physical science teaching in secondary school. **MS degree Thesis of National Changhua Normal University**. (in Chinese)

Nespor, J. K. (1985). The role of beliefs in the practice of teaching: Final Report of the Teacher Beliefs Study. (**ERIC Document Reproduction Service No. ED270446**)

Thompson, A. G. (1984). The relationship of teachers conception of mathematics and mathematics teaching to instructional practice. **Educational Studies in Mathematics**, **15**, p.105-107.

BEST COPY AVAILABLE

Tobin, K. (1992). Teacher learning and curriculum reform. Paper presented at a symposium at the annual meeting of the American Educational Research Association. (San Francisco, 1992)

Tobin, K.; Fraser, B. J. (1989). Barriers to higher-level cognitive learning in high school science. ***Science Education***, **73**(6): pp. 659-682.

Tuan, H. (1991). The influence of preservice secondary science teachers' beliefs about science and pedagogy on their planning and teaching. Paper presented at annual meeting of the National Association for Research in Science Teaching, Lake Ge neva, WI, 1991. **(ERIC Document Reproduction Service No. ED332871)**

理化科實習教師教學行為的時間序列分析研究

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摘　　要

有見於實習敎師第五年的實習敎育目標係提供實習敎師有機會將學校四年所學的敎育理論和敎育實務結合，並建構出符合實習敎師個人特質和時代需求的敎學知能。因此實習敎師第五年的學習成果，不但影響實習敎師本身的敎學知能，更影響整體敎育的品質，而且在實習的過程中更能看出實習敎師所學。有鑑於此，本研究將利用時間序列分析法找出實習敎師的主要敎學知能，以及欠缺的敎學知能。研究歷程將分爲三個不同階段：即在實習第一學期的期中和期末，以及第二學的期中，分別進行結構性和非結構性深度訪談、分類法，先找出一般發現，再利用歸納法找出主要看法，最後再利用歸納法，找出主要看法，然後再應用心理學、認知心理學、和知識等，以及歸納法、綜合法和推論法，找出主要結論。

本研究所獲得的結論如下：

結論1：個案實習敎信仰客觀主義（含理性主義和經驗主義）的科學知識觀。因此其敎學行爲均傾向以講解式爲主，而實驗敎學則以食譜式爲主。

結論2：個案實習理化敎師共同具有的敎學知能是（除本科專業知識外）：講解式敎學策略、將講課綱要抄在黑板上、引導學生學習（於問閉鎖式問題、要求學生動手解問題等）、控制敎室的秩序、待學生回答問題後，又重複扼要說明該問題的重要概念、食譜式實驗敎學法、控制實驗室的秩序，以及分組巡視實驗等。

結論3：實習敎師具有之相關敎學策略的敎學知能不足。

結論4：在上課進行中，實習敎師能應用的敎學策略不夠多，顯示其具有之敎學知能不足。

結論5：在實驗敎學中，實習敎師能應用之實驗室敎學策略不夠多，顯示其具有之實驗室敎學知能不足。

結論6：實習敎師具有之個別化敎學理論和個別化敎學策略的敎學知能不足。

結論7：實習敎師具有之有建構主義的科學知識觀和建構式敎學策略的敎學知能不足。

結論8：實習敎師具有之師生互動，和同儕互動等攸關認知學習的敎學知能不足。

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Ph.D. Students' Epistemological Commitments and Their Knowledge Construction

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ABSTRACT

This research was designed to examine Ph.D. students' epistemological commitments and their ways of research knowledge construction. Its subjects were six Cornell Ph.D. candidates. Their research fields covered physics, electrical engineering, microbiology, natural resources, economics, and development sociology. Basically, the choice of fields resulted from consideration for the balance of physical sciences, social sciences, and biological sciences. The average duration of their studies at Cornell was 5.3 years.

In the first interview, the students' epistemological commitments were revealed through their responses on six issues: observation, inquiry process, data, inquiry results, knowledge, and the development and growth of knowledge. The second interview was incorporated with Novak's concept mapping and Gowin's epistemological Vee to study the students' research knowledge construction.

This research showed that the students expressed different epistemological beliefs about different issues, so their overall epistemological commitments were not consistent, and their research knowledge construction was methodologically oriented, with emphasis on more methodological issues but less attention paid to the influences of theoretical issues.

Overall, the students held moderate positions while discussing epistemological issues, but they adopted a firmly logical positivist view in constructing their research knowledge. This suggested the dominance of logical positivism in school education and research settings; however, their moderate position on epistemological issues showed their awareness of the constructivist perspective.

Key words: epistemological commitments, knowledge construction, Gowin's epistemological Vee, logical positivism, constructivism

I. Introduction

Research on cognitive learning has gradually challenged the dominance of behavioral learning theories since the 1960s. However, only a few studies on the effects of students' epistemological beliefs on their learning have been conducted recently. These studies claim student epistemological commitments exert an influence on learning (Edmondson, 1989, Strike, et al., 1982, 1992, Confrey, 1980, and Waterman, 1982). Inspired by these studies, this research focused on students' epistemological commitments and their knowledge construction. Basically, the research consisted of two interdependent studies — one was to evaluate students' epistemological commitments, and the other was to investigate their ways of conducting research and constructing knowledge.

To understand students' epistemological commitments, which is the first focus of the research, will illustrate how they conceive the essence of knowledge, the changing nature of the development of scientific knowledge, and the role of human beings in the process of knowledge construction. Generally speaking, most students, including graduate students, may not be able to draw a distinction between constructivism and logical positivism — Edmondson's classification (1989), or between naturalism and positivism — Lincoln and Guba's categorization (1985). However, they do have certain epistemological beliefs, which are manifested in their research work and process of knowledge construction.

The study of knowledge construction, the other focus of this research, has a more concrete application in education. The investigation of the interactions among values, beliefs, theoretical foundations, methodologies, and knowledge claims will present rich and important information for instruction, learning, and curriculum design in graduate education.

II. Theoretical Foundation

1. Epistemological beliefs

Kuhn's work (Kuhn, 1970) claims that the development of knowledge throughout history clearly shows the interwoven relationships between epistemological beliefs and knowledge construction. In his view, a certain epistemological perspective guides associated research methodology and dominates the development of knowledge for a period of time.

Nussbaum (1989) classified alternative philosophical frameworks for studying the history of science as empiricism / positivism, rationalism, and constructivism. From his point of view, the division between empiricism and rationalism is their differences on the most substantial assumptions about the source of and the methods for validating human knowledge. Empiricism stresses the importance of the evidence of the senses as the source and validation of knowledge, while rationalism emphasizes the power of the intellect. Regarding the nature and the growth of knowledge, they share the same beliefs. Both of them believe the nature of knowledge is provable and confirmable, so it is absolute and true; and the growth of knowledge results from Man's finding out the existing true knowledge. However, constructivism has distinctive perspectives on the two issues. A constructivist perspective stresses Man's active role in the process of knowledge construction, and adopts a relative view on the nature of knowledge, assuming that knowledge is changeable and never confirmable.

Lincoln and Guba (1985) make clear the comparison between positivism and naturalism. They highlight the contrast — belief in absolute truth versus belief in contextual truth. They also discuss the relationship between researchers and research to point out that the involvement of individual conceptual frameworks in research is inevitable. As to the issue of epistemology, they endorse the importance of the relationship between knowing and the knower, rather than obscuring the knower in the process of knowing. They show the contrast of the two views on five axioms, namely the nature of reality, the relationship of knower to the known, the possibility of generalization, the possibility of causal linkages, and the role of values (Lincoln & Guba, 1985).

Regarding the nature of reality, in Lincoln and Guba's view, the positivist paradigm professes a "single, tangible, and fragmentable" reality, while the naturalist paradigm looks at reality as "multiple, constructed, and holistic." As to the issue of the relationship of knower to the known, they think the positivist paradigm has a dualistic view, while the naturalist paradigm believes in an inseparable and interactive relationship between knower and known. For the issue of generalization, Lincoln and Guba emphasize that the positivist paradigm asserts the possibility of time- and context-free generalization, but the naturalist paradigm insists generalization must be time- and context-bound. The fourth axiom is causal linkages. They argue that these are assumed by the positivist paradigm, but questioned by the naturalist paradigm. Furthermore, they point out that the naturalist paradigm agrees with correlation, rather than causation. Regarding the role of an individual value system in inquiry processes, they claim that the value-free inquiry endorsed by the positivist paradigm is impossible; by contrast, they agree with the claim of the naturalist paradigm that a value-bound inquiry is inevitable.

Edmondson (1989) classified epistemological beliefs into constructivism and logical positivism. She pointed out a major distinction between the two beliefs — the way in which knowledge is constructed. From the perspective of logical positivism, knowledge is discovered, and it is an "entity which is external to human experience", while in the view of constructivism, knowledge is constructed by human beings, and it is "always changing and being revised by people who incorporate new information with that which already exists."

Regarding the essence of knowledge, constructivism and logical positivism offer different explanations. Constructivists emphasize scientists' interpretation of events or objects, and thus acknowledge that the construction of knowledge is influenced by "conceptual goggles", i.e., theories and epistemological commitments. However, logical positivists believe knowledge exists by itself and is separate from human experience; therefore, knowledge is discovered, tested, and constant. In addition, the foundation of logical positivism is the belief in the unity of science and an absolute truth. Therefore, logical positivism employs the application of logic, mathematics and theoretical physics to pursue the final truth of the universe, and avoids meaning, personal feelings, and values in the inquiry processes. In contrast, constructivism asserts that knowledge construction results from people's interactions with the world, and thus knowledge construction has contextual and constructivist natures (Edmondson, 1989).

2. The perspectives of knowledge construction

Three perspectives of knowledge construction will be discussed. A generally accepted model of knowledge construction, called a traditional view by Waterman (1982), is from the perspective of natural sciences. Gowin (1981) proposed a view of knowledge construction from an educational perspective. A different model of knowledge construction is offered by Knorr-Certina (1981) from the perspective of the constructivist and contextual nature of science.

Waterman (1982) thought the traditional view of knowledge construction, which had been well accepted in school science education, was based on a combination of views from the empiricist, logical positivist, and Popperian falsificationist theories of science. She defined the term "traditional view of science" as "...an amalgam of elements of empiricism, logical positivism and falsificationism" (Waterman, 1982, p. 10).

The distinctive features of the traditional view of knowledge construction are its operational basis, existing external realities, the "hypothetico-deductive" model of scientific inquiry, and the falsification principle. The first two features are adopted from empiricist theories of science which emphasize the ultimate truth of existing facts, based on which hypotheses and generalizations are constructed and tested. "Hypothetico-deductive" reasoning is the main theme of logical positivism, which highlights the importance of logic and reasoning. Popper's falsification principle has enormously changed researchers' views about the theory of knowledge construction and influenced their research designs.

Gowin (1981) discusses the structure of knowledge from the perspective of education. Since he defines educating as an eventful process, he emphasizes knowledge as inquiry results or products, the criteria of which are "meaningfulness" and "excellence". He addresses knowledge construction through two perspectives: one is the logical analysis of the structure of knowledge, and the other is the pedagogical analysis of the materials of knowledge. He suggests five questions to analyze the structure of knowledge, which involve telling questions, conceptual structure, methods, knowledge claims, and value claims. Thus, he highlights the theoretical foundation and methodological concerns of the process of knowledge construction.

Besides the hierarchical structure in each side of Gowin's Vee diagram, Gowin (1981) explicates the interplay between the elements in both sides. Gowin's model of knowledge construction is dynamic and theory-driven. Novak and Gowin (1984) elaborate the conception of the continuous process of knowledge construction by illustrating a "parade of Vee diagrams" (Novak & Gowin, pp. 152 - 153).

Knorr-Cetina (1981) took an anthropological approach to analyze the production of scientific knowledge. She proposed a contrastive explanation of the process of scientific knowledge construction. Two major themes of her perspective are the constructivist essence and the contextual nature of science. She explicates how scientists fabricate scientific facts through a series of decision-making steps. In the process of chain decision-making, she highlights the inseparable relationship between discovery and validation to illustrate the constructivist essence of scientific knowledge construction. To corroborate her view of the contextual nature of science, she describes how the scientists choose their research focuses with consideration for the tastes of the editors of journals, and of the committee members of the NSF (National Scientific Foundation). She also points out the control and distribution of the resources of scientific knowledge by the so-called scientific elite.

Knorr-Cetina claims that scientific knowledge is internally structured, since the process of knowledge fabrication is based on a chain of decisions and negotiations by scientists. Scientific fabrication is based on previous results, and will be transformed in further fabrication. Instead of discovering facts, scientific knowledge construction has a constructivist essence. Furthermore, she points out that during the process of knowledge fabrication, the conception of logically deductive decision making does not exist. On the contrary, the incidence of indeterminacy of theory choices or research directions appears often. The selection of theories or research directions is usually based on negotiations among the scientists situated in time, space, and other contextual factors. The process is quite similar to selectivity in social studies.

III. Methodology

In order to understand an individual's way of thinking, no other data collection method might be as important as the individual interview. The individual interview is the most direct and accurate way of knowing what and how students think and feel. In the field of cognitive study, to probe people's thinking is important; however, it is not easy. Three relevant studies — Perry (1970), Belenky et al. (1986), and Kerr (1988), were successfully conducted to investigate people's thinking and feeling by using in-depth interviews.

This research was inspired by the above three studies to adopt the interview method to investigate Taiwanese graduate students' epistemological beliefs and knowledge construction. The planning and execution of the interviews followed the five elements and three steps explicated by Millar et al. (1992). The design of incorporating concept mapping and Gowin's Vee diagram to externalize the cognitive understanding and conceptual knowledge structures of my interviewees was adapted from Novak's approach (Novak & Gowin, 1984). The analyses of the interview data were based on Mishler's narrative analyses and highlighted the process of meaning making and feeling sharing (Mishler, 1986).

IV. Data Collection And Analysis

The research consisted of two interviews. The theme of the first interview was the students' epistemological commitments. With the discussion of the six issues — observation, inquiry process, data, inquiry results, knowledge, and the development of scientific knowledge, the questions in the interview covered both the students' practical research experiences and epistemological beliefs.

The second interview focused on how students conducted their research and constructed their research knowledge. Based on their individual research knowledge maps, the interviews proceeded with these focuses: research design, knowledge structure, and knowledge construction. The issue of their research designs was discussed based on the concept maps, and the focuses of their research knowledge structure and knowledge construction were investigated with discussion of Gowin's epistemological Vee diagram. The topical sequence of the questions was research focus, events and objects of research, theoretical foundation, and finally methodological issues. The theoretical foundation emphasized the influences of theories, philosophy, and world views, and the methodological base focused on their research records, transformations, knowledge claims, and value claims.

Six Taiwanese Cornell graduate students were the subjects of the interviews (Table 1). They were chosen with consideration of their willingness to participate in this research, and to balance gender and fields of study. Half of them were female and the other half were male. Their research fields covered physics, electrical engineering, microbiol-

Table 1. The Demographic Information of the Six Subjects

Name	Field of Study	Gender	Years at Cornell	Anticipated Graduation Data
Kevin	Electrical Engineering	Male	7 years	Summer, 93
Ann	Microbiology	Female	4 years	Summer, 94
Mark	Theoretical Physics	Male	5 years	Summer, 93
Kay	Natural Resources	Female	7 years	Summer, 93
David	Econimics	Male	4 years	Summer, 94
Susan	Development Sociology	Female	5 years	Summer, 93

ogy, natural resources, economics, and development sociology. Basically, the choice of fields resulted from consideration for the balance of physical sciences, social sciences, and biological sciences. One of the two subjects in the natural sciences was in theoretical physics, the other in electrical engineering. Biological sciences included a student of traditional biological study, the behavior of common terns, and a more recently developed field — molecular biology. The two students classified into social sciences were in economics and development sociology. All expected to graduate from Cornell in 1993-1994. The average duration of their studies at Cornell was 5.3 years.

Except for the student majoring in economics who was interviewed three times — once for his epistemological commitment and twice for his knowledge construction, the other five students were interviewed twice. Each interview took 45 minutes to 60 minutes to complete. With the interviewees' permission, a tape recorder was used to record the interview. The transcript of each interview was sent back to the interviewee for confirmation and comment. Transcripts of the interviews are 115 pages long (Chang, Appendix pp. 8-122, 1994).

The transcripts were analyzed to reveal the students' beliefs about the issues of objectivity, subjectivity, validity, and reliability, while discussing the essence of scientific knowledge, and to show how they dealt with the theoretical and methodological issues of knowledge construction while constructing their research projects. The analysis was descriptively oriented and very much based on the interviewees' narratives. A complete report was presented in Chang's Ph.D. dissertation (Chang, 1994).

V. Results And Discussion

1. Students' views on the epistemological issues

(1) Observations

A. Objective observation vs. subjective observation:

Can observation be objective? The answer will depend on what and how researchers observe. Kevin, using autocorrelators to observe the length of the optical short pulse, believed his observations were objective. He used the autocorrelators and other electrical equipment, such as an x-y plotter to record the data of the length of an optical short pulse, without the influences of individual subjectivity, so he was highly confident of the objectivity of his observations. However, Kay, observing the behavior of birds, disagreed that observation could be objective. She described the process of review of literature and observation as a trade-off. She said that any review of literature or prior knowledge would compromise a researcher's objectivity. She believed most researchers observed something already in their own minds, or simply found things to confirm their prior knowledge and ignored everything else. So the more one is influenced by review of literature or prior knowledge, the less he or she is able to find something new.

> *In your opinion, is it possible to have objective observation in research?*
>
> It is a good question. One question I was asked by my committee member during my Ph.D. dissertation defense was how I would instruct my students to conduct field research if I held a teaching job in a university. I think it is an issue of trade-off. You can let your students conduct their field observation without any instruction, so they may find something interesting that has not been mentioned before. If they read literature before they go out to observe, they would be restrained by what they have learned, and observe something described in the literature; in other words, they observe something to confirm their learning from review of literature. I have to emphasize again that it is a trade-off issue. My case is different from most researchers. I conducted my field observation of the behavior of common terns before I started my review of literature. It was beneficial to my research work (Chang's interview transcripts, P. 62).

The distinction between the two views results from the different purposes of observation. If the observation is conducted to find out some designated aims, then it can be objective, with the help of instruments, and researchers should try their best to make it so. However, if the aims are not yet defined specifically, then interesting findings usually come from the researchers, who tend to have a more open mind.

B. Observation and question formulation

In school science education, observation has been taught to be a key to formulating a research focus question. Observation is a way to intrigue people, and this curiosity is a motive for formulating a research question to explore. From the perspective of science, the development of knowledge has been a process of formulating research questions and pursuing the answers. Observation is just the first step in the process. The research of Kay in the field of natural resources demonstrates the process of producing knowledge successfully. She observed the behavior of birds in the first year of her research. She was interested in the differences of mate fidelity and site fidelity before and after a flood, and curious about the underlying forces of the phenomenon. She exactly followed the process described above to formulate her research focus question and then collected data, analyzed data, and finally proposed her explanations for the natural phenomenon.

However, focus question formulation does not necessarily result from the observation of an event or object for many other fields. Instead of observing a natural event, the graduate student in the field of economics formulated his focus question from intensive literature review. As he said, he reviewed many papers to understand the problems of the banking system and find out the real nature of the problems and the current endeavors of other researchers to deal with the problems. Then he formulated his question. He formulated his research focus question from examining the thoughts presented in the literature of his field.

> Literature described the natures and situations of the problems, and proposed approaches to solve the problems. I examined these approaches to see their merits and shortcomings; then tried to develop my own approaches to solve the problems from a different perspective (Chang's interview transcripts, P. 84).

This is not unusual. Many researchers in social sciences even conduct their analyses with secondary data. They do not observe to get data but simply analyze the data in the public domain. What they do is apply different analytic technology, different perspectives or more complex analysis to study a set of secondary data. The students in economics and development sociology in this study are good examples.

For most advanced research, such as Ph.D. research, the process of formulating a focus relies more on literature review. The role of direct observation might be integral for beginning science experiments in school laboratories, but may not for advanced and sophisticated studies.

(2). Inquiry process

A. *Subjectivity and objectivity in an inquiry process*

The inquiry process is inevitably influenced by researchers' cognitive frameworks. Therefore, the process is bound to be subjective, even though every researcher has to try to maintain as much objectivity as possible. The student in economics explained why his inquiry process was inevitably subjective. Regarding the question "Is it possible to have an objective inquiry process in your field?" he answered, "I don't think so, because choosing theories for an inquiry process is more or less subjective." In addition to choosing theories, the researcher also has to determine which factors will be considered when he builds his model and in what manner the data will be analyzed. David did acknowledge the value of objectivity, but he thought objectivity was an ideal and not possible to achieve in social science. Simply because there are too many factors related to and influencing the subject matter, the process of choosing some of them to use in an inquiry process involves subjectivity. Different perspectives among researchers would result in different factors and theories being considered and different theories result in different approaches, and different interpretations. He added that, "It's hard to judge which is better. You must consider situations, time, and other contextual factors."

> [...] I think the process of observation or reading the descriptions of problems is objective, but seeking solutions for the problems is somehow subjective (Chang's interview transcripts, P. 85).

The debate on subjectivity and objectivity in the inquiry process has been very intriguing recently. Objectivity has been emphasized with great enthusiasm in research inquiry because of the dominance of logical positivism and later post-positivism. However, the recent development of cognitive science has cast doubt on the objectivity of human perception, and, moreover, constructivism — a branch of the philosophy of science — challenges the feasibility of value-free research. No consensus has been reached yet. Even the definitions and content of objectivity and subjectivity are still very controversial (Eisner & Peshkin, 1990). To avoid a complicated consideration of the issue, Kevin, who conducted research into producing an optical short pulse, defined objectivity as the replicability of inquiry results. He said, "from the perspective of science, objectivity means the results of observation and an experiment can be the same if the researcher adopts the same procedures and instrumentation" (Chang's interview transcripts, p. 13). He chose the possibility of cross-examination and replicability as the criteria of objectivity. Therefore, he claimed his inquiry was objective, because anyone could repeat his research results if his procedures were followed and his instrumentation applied. However, he agreed that his inquiry process had been influenced by what he had been trained to do. He pointed out the importance of adding some "crazy ideas" to his research inquiry, so he would be able to get better research results.

> [...] I had an interesting personal experience in conducting my research. I remember that once my advisor recommended a way to produce a short pulse and confidently assured me it would work. But it did not work at all. He had been in this field for many years. He still made a wrong judgment. I think the reason is that the natural phenomena we are observing are unfamiliar to us or even unknown to us. It would be a mistake to adopt a standard procedure to probe an unknown phenomenon. Of course, borrowing experiences from other research is helpful, but it does not guarantee successful research. Therefore, I would like to emphasize the importance of individual creativity and even some crazy ideas (Chang's interview transcripts, P. 12).

Apparently, he divided the inquiry process into two sections to discuss the issue of objectivity and subjectivity, namely, formulation of an inquiry process and the procedure of an inquiry process. He argued personal subjectivity was inevitable in the process of formulation, while objectivity had to be maintained in execution.

B. Scientific inquiry vs. non-scientific inquiry

Regarding the distinctions of scientific and non-scientific inquiry, the usual perception that the inquiry adopted in natural sciences is scientific while that adopted in social sciences is non-scientific, was rejected by my subjects. Kay, a natural resources major, pointed out directly that it was wrong to categorize knowledge into science and social studies, because the categorization implies the inquiry of social studies is non-scientific. She said social studies could be scientific, if they adopted scientific inquiry.

As to the distinction between scientific inquiry and non-scientific inquiry, Mark, in theoretical physics, emphasized the importance of the underlying reasoning of research. He said the studies of humanities and literature could be scientific if the statements of their arguments were arranged logically; he added that the relationships between any statements were connected by causal relationships. It did not matter if there were data or not, and it did not matter if it was natural sciences or social sciences, either. The key point of a scientific inquiry is logical reasoning.

> If you define the inquiry process as one of data collection, conducting experiments, and analysis, it implies, by definition, a scientific inquiry process to explain nature. However, some fields do not relate to nature, such as social studies, humanities, and even literature. These fields do not have a process of collecting data, conducting experiments, and any equations, but I do not think their research is not scientific. Their research is the same as scientific research. However, even though the study of literature lacks data, experiments, and equations, the linkages among its statements are logical. If the statements in its arguments have logical relations, like the logical relations of science, I think it is scientific research (Chang's interview transcripts, P. 47-48).

Although both natural sciences and social sciences can be scientific, they do have significant differences in their focus subjects. The subjects of social sciences are people and all kinds of human systems, such as political systems, laws, and cultures, while the subjects of natural sciences are natural phenomena. Studies about people are more difficult to handle because people are more subject to change in different contexts and are developing all the time. One more difficulty mentioned by

David is that the influential factors are not able to be controlled; as a result, choosing important factors to be studied and ignoring everything else are necessary for social studies. Therefore, the results of social sciences are more likely to contain errors, and that is why the inquiry of social sciences are said to be non-scientific.

> I agree scientific methods are more objective. [...] It is very difficult for social science to be objective because there are too many factors. There is no way to control all the factors. The subjects of social science are human beings, either their thoughts, or behavior. People are changing all the time. It's impossible to control these factors like doing science in a lab. The focuses and subjects of social science are different from those of science (Chang's interview transcripts, P. 85-86).

(3) Data

A. The measurement of data

Except for research without data analysis, focus objects or research events must be measured and recorded before being processed and analyzed. How to measure data depends on the characteristics of the data itself. Most objects and events of natural science can be measured by using numbers, e.g., frequency, weight, length, and time. Whether the data is continuous or noncontinuous, it can be measured objectively and accurately, and some of my subjects agreed that if its data can be manipulated by adopting natural numbers, research can be recognized as reliable and scientific.

However, some events are not easily quantifiable. Most of them are related to humans, such as feelings, thinking, and attitudes. Usually, research on these issues is called social studies. In order to measure non-quantifiable events, rating scales and different coding systems are needed for transforming them into measurable data capable of being analyzed. Data coding and rating scales are two important issues of quantitative research in social studies. How to transform the data accurately is the concern of researchers of quantitative phenomena. The issues which have been discussed for a long time are reliability and validity.

Measuring to obtain data is very different in different fields. It ranges from very simple acquisition, counting and seeing, to very complicated techniques, such as an autocorrelator. Kay collected her data by catching and recatching birds and recording the numbers of bands, nests, and eggs. The data were obtained by observing, counting, and recording. However, Kevin, who measured the length of the optical short pulse, needed the help of a highly specialized technique to detect the movement of light waves.

Nowadays, the processes of data recording and data analysis can be effectively separated and performed by different agents. David, focusing on the efficiency of the banking industry, requested his data — balance sheets and income statements — from banks in Taiwan. Kay, studying the bird population, caught birds and then got the numbers from the bands on her birds. Finally, she requested information on the birds she caught from the bird banding library.

The development of computational power and statistical analysis has exerted a special influence on research with large amounts of data. Statistical analysis of large bodies of data helps find correlation, but not causal relations.

B. The guiding theory of data

The process of recording data can be objective and accurate, whether it is done by human perception or highly technical equipment, if we exclude the consideration of cognitive influences as an influencing factor that has been proposed by the psychologists of the Gestalt school. However, which data should be recorded and which data should be analyzed or adopted in research are affected by researchers' guiding theories. Mark, in the field of theoretical physics, gave a good example of the influences of guiding theory on data collection. He said presently useful data could be discarded and the "garbage" could become precious information later, simply with the switch of guiding theories.

> I cannot remember all the details of the example. It is regarding synchrotron radiation, which is emitted by high energy charged electrons. The radiation provides good data for scientists. But in different theories, scientists focused on different parts of the radiation. At the beginning stage of the study of synchrotron radiation, most scientists were interested in the data in the range of infrared radiation, because their guiding theories assumed these data would be useful. They looked at the data from ultraviolet radiation as "noise" or "garbage". However, 10 years

> later, the guiding theories changed, and the data which had been regarded as noise or garbage became more interesting and informative (Chang's interview transcripts, P. 49).

Also, the case of Kay, who conducted her field observation in her first year of research work, demonstrates another good example of the influences of guiding theory. She collected a large amount of data in her field observation, but she did not use all of it when she proceeded with data analysis. She discarded some data which were not needed, and went to collect more. The criterion for choosing data was its potential for analysis. She used the term "interesting" to describe the potential of data. Obviously, her choice is governed by her theories. Therefore, theory-laden research is inevitable.

(4) Inquiry results

A. The repeatability of inquiry results

In my impression during the interviews, an important criterion for objective and scientific research is the repeatability of its inquiry results. David, in economics, said his inquiry result could be repeated if anyone followed his approach using the same data and analytic methods. However, he added that although the result of the analysis was repeatable, the interpretation of the result depended on a researcher's subjectivity. He used an example to show how different interpretations resulted from the same phenomenon. The example was regarding the theory of interest spread.

> Interpretations may be subjective. For instance, the theories of interest spread can be that either monopoly market power increases the interest spread because of no competition, or monopoly market decreases the interest spread because scale operation produces more profit that makes the decrease of interest spread possible. They are two contradictory theories. You may choose one of them, based on your interpretation, condition, and, ... (Chang's interview transcripts, P. 88).

The experiment in producing the optical short pulse is repeatable, too. Kevin, in electrical engineering, said his research was empirical, and the replicability of research results was an important concern, so his research result had to be repeatable.

Regarding the issue of repeatability, Kay discussed her two studies: population model and the relationships between mate fidelity and site fidelity. She thought the result of the population model was repeatable, because the common tern population lived there and would not change too much in a couple of years. However, the result of the research on mate fidelity and site fidelity might not be repeated, because the flood in the third year was a natural event which could not have occurred by human design. It is true humans cannot control some natural events, but to some extent, a flood can be simulated by scientists. Kay modified her opinion about the repeatability of the influences of the flood by pointing out that if someone controlled the water level of the canal around Oneida Island, this would produce a similar effect.

Some would argue that nothing can be repeatable, because the flow of time never stops. This is true. However, the goal of research is to discover the relations among factors in general phenomena. Thus, any specific phenomenon can be generalized to a "big picture" for further study. For instance, in the research of mate fidelity and site fidelity, the influence of flood is the concern — which particular flood is not the issue at all. As my subject suggested, if we adopt the concept of relative time and set a variable for time, then we can set "0" at the beginning of research. As a result, the argument based on the concept of absolute time can be avoided.

(5) Knowledge

A. The content of knowledge

The content of knowledge defined by my subjects are different. Knowledge was defined by David, focusing on developing, testing, and applying an economic model of the banking industry, as something that can explain natural phenomena, has practical application, and has the power of prediction. The definition emphasizes the functions of knowledge — explanation, application, and prediction.

Kevin in the field of electrical engineering gave a different view on knowledge. He divided it into scientific knowledge and theology. He did not define the content of the two forms, but he described the relationship between them by saying that scientific knowledge was derived from theology.

> I usually divide knowledge into two kinds of knowledge: one is scientific knowledge, and the other is theology.
> [...] Generally speaking, the difference between the two forms is the objects they deal with. Moreover, I think scientific knowledge has been derived from theological knowledge. I am not saying that we can understand scientific knowledge just by studying theological knowledge. What I really mean is the structure and reasoning of scientific knowledge are explainable from the perspective of theology. [...] From the perspective of theology, God created people, the world, and the Universe. When He created everything, He put an order into it. What science has been looking for is the order. Many scientists struggle for a universal and unified law to explain all phenomena; in other words, they are looking for the order put there by God. Newton's law of motion is a good example. The law explains the order in the phenomenon of motion (Chang's interview transcripts, PP. 14-15).

Mark, in theoretical physics, emphasized the value of reasoning, so he categorized knowledge into two categories: one was natural raw data and their derived fundamental theories, such as Newtonian laws and Einsteinian theories; the other was the reasoning underlying these theories and laws. He added that the power of reasoning could help develop new theories and transform current theories to different contexts. This definition highlights the importance of reasoning, and, on the other hand, devalues the role of raw data by putting raw data and fundamental theories together.

Like the researchers above, Ann, in the field of biology, defined knowledge from the view of her discipline, in this case, biological science. She roughly categorized knowledge into humanities, natural sciences, medical knowledge, and biological knowledge. As to the content of knowledge, she divided knowledge into that obtained from observation and that obtained from interpretation of the observation. She said that "the raw data discovered by humans is knowledge, and the interpretation of these raw data is knowledge too, such as Einstein's theory, $E = mc^2$" (Chang's interview transcripts, p. 71).

B. The knowledge of social sciences vs. scientific knowledge

The major difference between the knowledge of social sciences and scientific knowledge is their subjects. The subjects of social sciences are people and all kinds of social systems, while the subjects of natural sciences are all sorts of natural events and materials.

The characteristics of the subjects of the two branches of knowledge are quite different. The consensus of the students was that people and their social and other systems are sophisticated and subject to change in different contexts. As a result, the knowledge of social sciences is relative and changeable, while the knowledge of natural science is absolute and changeless. For example, Kevin described the subjects of social sciences as "changeable, unpredictable, and influenced by contextual factors" (Chang's interview transcripts, p. 15).

Kay stressed that research on people and their civilized systems was more difficult to handle by comparison with any animal study. The student focusing on human fertility behavior emphasized the change of human thinking and feelings and pointed out that change in the knowledge of social sciences was expected. Since people and their social systems are dynamic and developing all the time, the knowledge of social sciences is always changing and developing.

However, scientific knowledge is recognized as changeless and absolute. In contrast to the subjects of social sciences, the subjects of natural sciences are changeless and easy to manipulate for study. Although scientific knowledge has being changing and developing, it is relatively stable by comparison with the social sciences.

The process of digging out data is another distinction between social science and natural science, as claimed by the student in theoretical physics. The process of data collection is more difficult to handle and even more fault-ridden in social sciences than in natural sciences. Thus, the results of social sciences are more subject to change, while scientific knowledge is repeatable and real.

Susan, in development sociology, pointed out that, unlike scientific knowledge, which is convincing by itself, conducting a social study was like telling a story; researchers had to explicate the contextual factors, the development of the study, the results and their interpretation in order to convince the readers.

(6) The development and growth of knowledge

Mark, in the field of theoretical physics, gave another good example to show the development of quantum field theory during the 1960s and 1970s. His example showed the challenges of a theory, competition of different theories, and the choice of a "paradigm"; in other words, it showed a development that included "normal science" and "extraordinary science".

> [...] In the 1960s, the researchers in the field of high energy physics did not think that quantum field theory was important, because the theory had some serious difficulties, and was not able to offer solutions. [...] Quantum field theory was not able to be renormalized at that time, and it was a serious challenge. In addition, the quantum field theory was not able to explain the force between photons and between quarks. At that time, researchers did not know how to solve these challenges; as a result, 99% of researchers switched to other theories, such as Regge trajectory, and abandoned the quantum field theory. [...] New phenomena were found by researchers at Stanford in the 1970s, and they could be explained only by the quantum field theory. And some serious challenges to quantum field theory were also overcome at the same time. Therefore, the quantum field theory became mainstream again. For instance, graduate students in the 1960s were not able to learn quantum field theory from textbooks or lectures. Instead, they learned the Regge trajectory, or something else. However, the quantum field theory has become a major feature of graduate textbooks and lectures since the 1970s (Chang's interview transcripts, PP. 51-52).

The biggest change to the framework of the field of biology occurred in the 19th century. It was initiated by Darwin's evolutionary theory. The switch from creationism to evolutionism resulted in the dramatic development of biological science during the past hundred years.

> Darwin developed his theory of evolution from his observations of nature. Nowadays, when we observe and study biological phenomena, we are more or less applying evolutionary perspective to interpret them. [...] The theory of evolution has tremendous influences in the field of biology. No matter whether you study animal behavior or conservation, you always adopt an evolutionary perspective to interpret your research results (Chang's interview transcripts, PP. 72-73).

There are good examples to show the development of theories in the field of economics, too. A familiar example is the development of stagnation theory. Based on the framework of economic theories, recession would always come with low priced commodities, but the recession of the 1970s brought on high commodity prices. The event changed basic economic theories, and stimulated the development of theories of stagnation.

> The economic theory that inflation always comes with prosperity had been acceptable before the great depression of the 1930s. Inflation with recession— stagnation, occurred in the 1930s, and the 1970s. The economic theories had to be modified and changed to explain the new phenomenon (Chang's interview transcripts, P. 90).

Susan, in development sociology, gave a different perspective of changing theories and knowledge. She attributed the dynamics to changing and context-dependent research events and objects. Because human thinking and feelings are changing, and their developed systems are dynamically interdependent, and because the results of social studies depend on contextual factors, the changing of theories and knowledge is expected. She used her research focus to support the perspective. People's fertility behavior changes at different periods of time, so the theories developed to explain it must have different considerations of contextual factors.

> [...] Obviously, people and society are more dynamic than the materials in natural sciences. Therefore, the changing of the results of social studies which are dependent on contexts is expected.
> [...] fertility behavior is different between 1980 and 1986. Obviously, people's fertility behavior has been changing all the time. It's quite convincing that the influential factors on fertility behavior have changed, and they will be continuously changing under different value systems and in different con-

texts (Chang's interview transcripts, pp. 113-114).

2. Students' research designs and knowledge construction

(1) Research designs

A. Experimental research design

Conducting an experiment and deductive reasoning are two major elements of experimental research design. Experimental research usually requires conducting experiments in a laboratory. The conducting of an experiment includes two important features: the manipulation of factors and the rigorous control of conditions. Deductive reasoning is the framework of an experimental design.

The research of the microbiology student illustrated a model of experimental design research. She began to mutate bacteria, tested the mutants' activity, found the mutants without activity, and finally investigated the mutated genes of these mutants. Her experimental design was a well designed process to investigate the genes which were the real "players" of the regulation process in nitrate assimilation.

> The reasoning of my experimental design is very straightforward. Since the gene will be regulated to promote the process of nitrate assimilation, if a bacterium can't perform the process with the presence of nitrite/nitrate and nasR, the gene I'm looking for must be missing from the bacterium, and thus if I can find out which gene is missing from the bacterium, I'll know the answer. The first design of my experiment is to mutate bacteria to damage their genes. Each bacterium has different damage. After the mutation, I test the bacteria to see which mutants lose the activity with the presence of nitrate or nitrite, and then separate the mutants from other bacteria. Finally, I examine the damaged gene and sequence its structure (Chang's interview transcripts, p. 35).

Her experiment did not stop there. Before she could make sure her discovery was a real player, she had to test it many times. She said, "Of course, I will use many approaches to check the gene and confirm its function in the regulation process" (Chang's interview transcripts, p. 35). The process of confirmation is crucial in experimental design research. Without it, her discovery — the promoting genes of the process of regulation — might be in error. She had to make a comparative experiment to study the activities of bacteria with the genes and without the genes to confirm that the genes were the real cause of the activity of nitrate assimilation.

Obviously, her experimental design demonstrates the two elements, an experimental design characterized by the manipulation of factors and rigorous control of conditions, and deductive reasoning. The procedures of mutating bacteria, presenting nitrite or nitrate, and taking out proteins are the research manipulations. The process of testing the activities of the bacteria with and without certain proteins obviously must be well controlled; otherwise its results may be defective.

B. Non-experimental research design

Non-experimental research design is usually intended to investigate the underlying correlation among the factors of an event. In contrast to experimental research design, non-experimental research design usually cannot manipulate its research events and cannot control its factors and conditions to compare its research results.

Non-experimental research design has some distinctive features: its event is usually continuous; its purpose is usually to build a model or theory to explain a past event and then to predict its trend; its general research schema is called modeling, rather than conducting an experiment in experimental design research; and its analytical tool is statistical analysis.

The nature of non-experimental research events or objects is continuous and changing. The research events and objects of the students in development sociology and economics illustrate this changing and continuous nature well. Her (the sociology student) research event was the duration of the first child birth interval. It was obviously continuous, and changing all the time. Susan attributed the change to differing value systems, cultural perspectives, and social systems. The research event of the economics student was the economic activities of the commercial banks in Taiwan. Apparently, this event is continuous and changing, too. The factors influencing the activities of banks can be social systems, cultural systems, economical systems, etc. David focused on one factor of the economical system — the influences of governmental economic policies on the expansion of bank credit.

Since their research events are continuous and changing, researchers have to artificially treat them as several complete events with beginnings and ends, based on their assumptions or on conventional considerations. For example, the economics student separated his event into three periods according to the status of governmental economical policies. The student studying the fertility behavior analyzed the data for the year 1980. It is a conventional approach to examining yearly human fertility behavior.

The goal of a non-experimental design research is usually to find the correlation among important factors behind an event. In contrast to experimental research design, which usually looks for causal relations by manipulation and controlling factors and conditions, non-experimental research design is always examining the correlation among factors (or independent variables) and its event (or its dependent variable). For instance, the microbiology student was looking for the promoting genes which could activate the regulation process of nitrate assimilation, and the student in electrical engineering incorporated the ideas of the integrated absorber and angled facet into the mechanism of a semiconductor laser to produce an optical short pulse. Obviously, both of them were searching for causal effects. However, the relations between people's fertility behavior and their economic status, family structures, and demographical factors are correlational rather than a causal relation.

Model building was a mainstay of the non-experimental research designs of the students in economics and development sociology. They had to build their models to guide their data analyses. According to their models, they decided which factors should be studied and which could be neglected. For example, the student in development sociology adopted three core factors, namely demographic factors, socio-economic status, and family structures, to build her own model for the analysis of people's fertility behavior. Thus, she studied the correlation between the three factors and her research event — the duration of the first childbirth. Similarly, the economics student applied Tobin's two views of bank credit expansion and incorporated equilibrium and disequilibrium hypotheses to build four analytical models for the analysis of the banking activities during three periods of time. Model building has been a major endeavor of my subjects' research in social sciences. The tests of their models were easily conducted with the help of computer statistics packages.

Statistical analysis has often been applied in non-experimental research design. The basic goal of non-experimental research is to test if the relation between the event — a dependent variable — and the theories — independent variables — is significant, and if the theories can offer a good explanation of the event. A statistical regression method is usually applied to analyze the correlation between independent variables and a dependent variable, and to estimate the influences of the independent variables. The regression analysis can offer three important insights into the power of a researcher's model: first, whether the model can offer a good explanation of its event; second, whether the influence of a certain factor is significant to the event; and third, the strength of the influence of a certain factor on the event.

The student in theoretical physics offered a different perspective on research design. His research was based on deductive reasoning and computation. One of his research designs was to replace the assumption of continuous space-time with discrete space-time in the topological theory, and then compute the results and compare the results from the two assumptions. Obviously, his research was not an experimental design. His research was a non-experimental design but was not quite like the ones discussed above.

(2) Methodology oriented research knowledge construction

Gowin (1981) proposed that a process of knowledge construction should include methodological and theoretical perspectives, as well as research focus questions and events and/or objects. His reasoning was that theoretical concerns and methodological issues are correlated and mutually dependent. Theoretical concerns lay a foundation for inquiry, and then knowledge claims and value claims from the inquiry expand the domain of theoretical knowledge. The process of knowledge construction is continuous. Theoretically, the theory of interdependent interaction between the theoretical concerns and methodological issues of research is convincing. However, during the interviews, I found all my subjects were very confident in the methodological issues of their researches, while they were not able to explicate the underlying theories, philosophies, and world views of their research, and how these theoretical concerns guided their researches.

The student in electrical engineering described in great detail how to incorporate the ideas of the integrated absorber and angled facet into the passive mode-locking semiconductor laser mechanism to produce the optical short pulse.

> The device for APM and CPM is not available on the market, so I had to make it by myself. The device needed two important features: an angled facet and an integrated absorber. I have studied the angled facet since I started working on Active Mode-locking. Although it turned out not to be successful, I applied the idea to my current research and found it got very good results. I arranged the directions of the angled facet to control the directions of the short pulse, so I could have either APM or CPM. The other feature was the integrated absorber. As I mentioned, a saturatable absorber is necessary for the Passive Mode-absorber. The technique of producing a saturatable absorber has been developed, but it is not an easy task. In order to build a device with the two specialties, I spent two years learning semiconductor processing, which includes RIE, CAIBE, CAD, photolithography, and chemical etching. Then, I spent one year building the device. The process of device fabrication is very delicate. For instance, I spent several months examining the surface of the angled facet to check if it was good enough for the research (Chang's interview transcripts, pp. 19-20).

His description illustrates methodologically oriented research very well. His research focus was to fabricate a device which was incorporated with his ideas to produce better optical short pulses. In order to achieve his research goal, he had to spend two years learning the techniques of semiconductor processing, one year building his device, and several more months testing his angled facet design.

The microbiology student's research focus was to investigate the promoting genes of the regulation process of nitrate assimilation. She said her experimental design was to locate the region of the promoting genes, to investigate their structures, and to test her discovery. In contrast, she indecisively mentioned a couple of theories, such as the two component regulator system, nitrate assimilation, and sequencing gene structures, to reply to the question about her guiding theories.

> [...], I thought of the evolution theory in biology and ecology when you asked the question. However, I was not able to think of any theory like Darwin's evolution theory in my field. The two component system, nitrate assimilation, and sequencing gene structures are theories which have important influences on my research design (Chang's interview transcripts, p. 39).

However, she was not able to clearly explain how these theories guided her research design. Instead, she pointed out that her research design was based on previous research results.

> I don't think I can give you a fundamental theory which my research is based on, but I believe our research has a connection to previous research. In other words, our research is based on the results of previous research work. For example, my current experiment to find the genes regulated by the nasR in the process of nitrate assimilation is based on the knowledge of gene structures of nasA, nasB, [...] ,nasF from my previous experiment. Although every lab in the field of molecular biology usually has its unique specific and narrow focuses, I believe there is something in common to connect every lab's research results together. (Chang's interview transcripts, p. 39).

The student who conducted her research on the population dynamics and breeding ecology of the common terns on Oneida Lake, New York, explicated her field observations, data recording, data transformation, statistical analyses, and results interpretation during the interview. She was very confident in describing how she dealt with the above methodological issues, but she was not very sure about the theories, philosophy, and world view of her research.

The students in development sociology and economics needed theories to build their models and to analyze their data. The economics student used the theories of bank credit expansion and the consideration of equilibrium and disequilibrium hypotheses to build his models, and the student in development sociology included the considerations of economic status, demographic factors, and family structures in her model. However, except in using those theories to build their models, they were quite confused about the influences of their theories, philosophies, and world views on their research design. In contrast, both of them clearly understood their methodological issues during the interview.

(3) Paradigm vs. guiding theories

Novak & Gowin(1984) claims that this process of knowledge construction will be more productive if its research is theory-driven. However, during the interview, most of my subjects had difficulty in elaborating how their theories guided their research. For example, the student in development sociology was not able to explicate the fundamental guiding theories of her research. She pointed out that her research was an interdisciplinary study, so her theories were too diversified to be generalized into certain fundamental ones.

> There are some theories guiding my research. I don't think there is one general or fundamental theory to guide the research of population development. As a matter of fact, the study of population development is an interdisciplinary field, which borrows theories from economics, sociology, population models, and many other fields. For instance, the factor of child value plays an important role in fertility behavior. Obviously, we have to analyze the factor from the perspective of economics. Besides, the theory of fertility transition is important for my research, too. Anyway, my research is guided by some well known theories, but it's difficult to specify each of them (Chang's interview transcripts, p. 117).

Similarly, the economics student said that if the ideas or principles he got from his review of literature were counted as the theories of his research, then his theories would be too many to be mentioned. He also admitted that he was not trained to consider thoroughly the influences of his theories, philosophy, and value beliefs on the way he conducted his research.

> [...] I think we are not used to discussing knowledge construction through the explanations of principles, theories, philosophy, and world views of our field. However, it doesn't mean we don't need theoretical perspectives on our research. Undoubtedly, we need literature review to build up a theoretical foundation for our research. Perhaps, we are just not trained to discuss the issues of principles, theories, philosophy, and world views separately (Chang's interview transcripts, p. 57)

These students were not used to discussing research knowledge construction through scrutinizing its guiding theories, epistemology, and value claims. However, this did not indicate their research was not theory-driven. They did have theories to guide their research, because they were able to point out some theories on which their research was based. However, they did not scrutinize their theories, philosophy, and value beliefs to design their studies. As a matter of fact, most of them applied more or less standard research designs in their fields to study new objects or events. For example, the student in microbiology used a very standard process of sequencing genes, testing bacteria activity, mutating bacteria, and examining the structures of mutated genes to study her interest, which is a completely new field. Her research focus was the promoting genes which would be regulated by the regulator, nasR, during the process of nitrate assimilation. She chose the topic because it was challenging and interesting.

> The study of the regulation of the genes or the region of the DNA in the bacteria, *Klebsiella pneumonia*, is a very new field. My advisor has spent six years studying the regulator, nasR, in the process of regulation to promote nitrate assimilation, but he hasn't started to study my research focus. Therefore, it is brand new territory. It's quite interesting and challenging. I believed I would learn a lot from the research. This has been a strong motivation for me to conduct the research (Chang's interview transcripts, pp. 37-38).

Apparently, the above description also illustrates the link between her research focus and her advisor's research. She followed her advisor's research efforts to explore a new topic. She might not be able to clarify the theoretical perspectives of her research, but her research was definitely based on certain theories, philosophies, and world views.

In fact, all my subjects had some theories for their researches. For instance, the student in economics constructed his own models by adopting current theories and hypotheses, incorporating of some contextual factors of Taiwan.

> How do you construct your models?
>
> According to Tobin's classification, there are two views of the process of bank credit expansion. The two views, known as the old view and the new view, have different emphases on economic factors. For instance, the old view emphasizes the monetary nature of credit expansion, while the new view focuses on the influences of the market system. By incorporating the two views with the hypotheses of equilibrium and disequilibrium, I can construct four models, namely, the old view with the equilibrium hypothesis, the old view with the disequilibrium hypothesis, the new view with the equilibrium hypothesis, and the new view with the disequilibrium hypothesis (Chang's interview transcripts, p. 99).

The student in development sociology used a similar approach to build her own model. She determined which factors should be included in her model according to her theories, and quantified these factors for measurement and analysis. She described how her theories guided her research as follows:

> Would you tell me how the theories guide your research?
>
> According to the theories, I know which factors are important to fertility behavior and should be included in my model. For instance, based on the theory of the influences of economic concerns of a couple on their fertility behavior, I have to choose suitable factors to reflect the effect. Also, I have to quantify the factors for further analysis. The process of choosing factors and quantifying them for computation is called "operationalization." For example, from the perspective of economics, the factor of child value will influence the fertility behavior. The idea is convincing, but the question is how to measure the child's value. Back to your question, theories help me choose important variables to form my model, and measure the variables for statistical analysis (Chang's interview transcripts, p. 117).

In conclusion, I believe their research is theory-driven. Although they did not scrutinize how their theories, philosophy, and value beliefs guided their research, they did accept the "paradigms" of their fields, so they either followed standard research designs or modified accepted approaches to conduct their research. The standard research designs and accepted approaches were based on certain "paradigms", in which theories, philosophy, and values had been assumed.

(4) Epistemological commitments and research knowledge construction

During the two interviews with each subject (three interviews with the economics student), I found they were willing to accept the constructivist perspective when they discussed their epistemological beliefs, while they all stuck to the logical positivist view to discuss conducting their research. While my subjects talked about epistemological issues, they discussed the issues of observation, inquiry process, data, inquiry results, knowledge, and the development and growth of knowledge from both constructivist and logical positivist perspectives, and most of my subjects did not express strong disagreement with either constructivism or logical positivism. For instance, none of my subjects thought social studies as non-scientific, nor excluded researchers' subjective interpretation from the process of knowledge construction. Some of them even accepted the concept that research results would be different due to different subjective interpretations based on either different theories or different contextual considerations. The conception of absolute or sole truth was doubted by my subjects. Also, they all agreed that knowledge is both evolving and changing, and they all were familiar with the switch of theories in the development of scientific knowledge.

However, my subjects were more oriented to logical positivism when they talked about their research knowledge construction. They stressed scientific and objective methodology to be an important element of their research. The student in electrical engineering highlighted his reliable and accurate electronic instruments in his research. A well designed experiment was emphasized by the student in microbiology. Building a model or applying an accepted model, statistical analyses, and hypothesis testing were endorsed by the students in economics, development sociology, and natural resources. The consistent reasoning of logic and mathematics was valued by the student in theoretical physics. These methodologies are well known to be scientific and standard in both natural and social sciences.

That my subjects' epistemological beliefs were inconsistent with their commitment to research knowledge construction can be easily shown with a comparison between the two interview transcripts. The student in electrical engineering had a logical positivist commitment to his research work. For example, he emphasized he was an experimental scientist in the field of applied sciences, so his research results must be repeatable and have empirical applications. However, he did show a constructivist tendency when he discussed the issue of objective observation. Although he insisted his observation, with the help of highly technical instruments, could be reliable and objective, he admitted it was still based on the assumption that the speed of light is constant, and if the assumption were rejected, then his observation results would be meaningless. Also, he highlighted the importance of individual creativity and "crazy ideas" in his inquiry process. This view implies the influences of an individual cognitive framework on his inquiry process. In addition, he thought that discovered facts and scientists' explanation and interpretation were mutually interdependent.

> Do you think knowledge is discovered facts that exist, or our interpretations and explanations of the discovered facts?
>
> Originally, I thought scientific knowledge was discovered facts, but after I heard the second part of your question, I would like to count the explanations and interpretations of these discovered facts as knowledge too. Both of them are important, and mutually interdependent (Chang's interview transcripts, p. 15).

The microbiology student is an experimental scientist, too. She apparently held logical positivist commitments on her knowledge construction, and the logical positivist view on some epistemological issues. However, she emphasized the necessity of "sharp observation" to notice something interesting and important behind concrete events or objects. In addition, she agreed that an inquiry process would be limited by theories. She gave her own experience to illustrate the constraint of theories in the interview.

> Ideally, we should try our best to overcome the constraint of our theories. We have to keep our minds as open as possible. I did have the experience of being restricted by my own theories last semester. I was depressed for a whole month. [..]
> I was depressed because for one month I was not able to get a result that I had been anticipating. Based on my theory, I believed there was something in a certain region of a chromosome, and I conducted many experiments to find it. I failed to find it even though I tried all kinds of methodologies, including my own methods and well known methodologies — until a postdoctor in my laboratory accidentally determined that the thing I was looking for might be in a different region. As a matter of fact, I didn't believe him, but I kept his idea in my mind. However, his idea opened my mind to doubt my theory. I kept doing experiments to find out what was going on. Finally, by an independent experiment (a different approach), I proved the postdoctor was right, and I was wrong. (Chang's interview transcripts, pp. 27-28).

In contrast to the two experimental scientists, the students in development sociology and economics had strong constructivist perspectives on epistemological issues, but conducted their research "scientifically" to legitimize their knowledge construction. For example, the student in development sociology admitted that an inquiry process could not be objective, because it would be dependent on researchers' models, methodology, and interpretation. However, she emphasized that most of her data could be quantified, such as the numbers of children, the first birth interval, and the years of marriage, so her research results were more reliable.

> I think the issue of objectivity in the process of interview or survey is more serious in some social studies, especially anthropology. However, in the field of population study, it is not so serious, because the answers to our questions are usually numbers, such as the number of children, the first birth interval, and the years of marriage. The response to our question is more objective. The errors of

> the responses are more systematic, and can be corrected by applying certain methods. For instance, the heaping effect can be corrected (Chang's interview transcripts, pp. 107-108).

Similarly, the economics student agreed with the inevitable interference of researchers' theories and interpretation on inquiry processes, but he emphasized that researchers should try their best to reduce the subjective interference. His way to avoid it was to rely on statistical methods for data analyses. Statistical analysis was recognized as a scientific method for social sciences by the student. This also confirms the description of the student in natural resources about the popularity of statistical analysis and mathematical models in publication.

To answer the question of whether their research was scientific, most of the students used two reasons to support their claims of scientific research: scientific methodology and repeatable research results. Using scientific methods made certain the validity of their research, and the repeatability of research results showed their research reliability. Obviously, they employed the logical positivist perspective to construct their research knowledge.

My subjects did not criticize the perspective of constructivism when they discussed their epistemological commitments, but they did favor logical positivism when they conducted their research. This tells us two things: one is that the concept of knowledge construction has been influenced by logical positivism in both school education and professional research institutions; the other is that, due to the development of cognitive studies and interest in historical studies of scientific knowledge, the roles of cognitive structures, personal value systems, and contextual effects in the process of knowledge construction have been recognized.

VI. Conclusions

This research showed that the students expressed different epistemological beliefs about different issues, so their overall epistemological commitments were not consistent, and their research knowledge construction was methodologically oriented, which emphasized more methodological issues but paid less attention to the influences of theoretical issues.

Overall, the students held moderate positions while discussing epistemological issues, but they adopted a firmly logical positivist view to construct their research knowledge. This suggested the dominance of logical positivism in school education and research settings; however, their moderate position on epistemological issues showed their awareness of the constructivist perspective.

Reference

Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's Ways of Knowing.* New York: Basic Books, Inc.

Chang, T. (1994). *Taiwanese Students' Epistemological Commitments And Research Knowledge Construction .* Ph.D. Thesis, Cornell University, Ithaca, NY.

Confrey, J. (1980). *Conceptual Change, Number Concepts And The Introduction to Calculus.* Ph.D. Thesis, Cornell University, Ithaca, NY.

Edmondson, K. M. (1989). *The Influence of Students' Conceptions of Scientific Knowledge And Their Orientations to Learning on Their Choices of Learning Strategy in a College Introductory Level Biology Course.* Ph.D. Thesis, Cornell University, Ithaca, NY.

Eisner, W. E, & Peshkin, A. (1990). *Qualitative Inquiry in Education—The Continuing Debate.* New York, N.Y.: Teachers College Press.

Gowin, D. B. (1981). *Educating.* Ithaca, N.Y.: Cornell University Press.

Kerr, P. (1988). *A Conceptualization of Learning, Teaching And Research Experiences of Women Scientists And its Implications for Science Education.* Ph.D. Thesis, Cornell University, Ithaca, NY.

Knorr-Cetina, K. D. (1981). *The Manufacture of Knowledge: An Essay on the Constructivist And Contextual Nature of Science.* Oxford: Pergamon Press.

Kuhn, T. S. (1962, 1970). *The Structure of Scientific Revolutions.* Chicago: The University of Chicago Press.

Lincoln, Y. S. & Guba, G. E. (1985). *Naturalistic Inquiry.* Newbury Park, California: Sage Publication, Inc.

Millar, R., Crute, V. & Hargie, O. (1992). *Professional Interviewing.* New York, N.Y.: Routledge, Chapman, and Hall Inc.

Mishler, G. E. (1986). *Research Interview Context And Narrative.* Cambridge, Massachusetts: Harvard University Press.

Novak, J. D. & Gowin, D. B. (1984). *Learning How to Learn.* New York: Cambridge University Press.

Nussbaum, J. (1989). "Classroom Conceptual Change: Philosophical Perspectives." *International Journal of Science Education*. 11. pp. 530 - 540.

Perry, W. G. (1970). *Forms of Intellectual and Ethical Development in the College Years.* New York, N.Y.: Holt, Rinehart and Winston, Inc.

Strike, A. K. & Posner, G. J. (1992). Revisionist Theory

of Conceptual Change. Duschl, R. A. & Hamilton, R. J. (eds). *Philosophy of Science Cognitive Psychology, And Educational Theory And Practice.* Albany, NY: State University of New York Press.

Strike, A. K. & Posner, G. J. (1982). Conceptual Change in Science Teaching. *European Journal of Science Education.* *4*(3), pp 231 - 240.

Waterman, M. A. (1982). *College Students' Beliefs About Scientific Knowledge: Foundation for Study of Epistemological Commitments in Conceptual Change.* Ph.D. Thesis, Cornell University.

博士班學生對知識本質的態度及建構知識的研究

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摘　要

本研究的研究目的是瞭解博士班的學生對知識本質的看法，及他們如何經由做研究及撰寫論文而建構知識。本研究的研究對象爲六個就讀於康乃爾大學的博士候選人，其中兩人屬於社會科學：發展社會學與經濟學；兩人爲生物學領域的研究者：微生物學及自然資源；另外兩位則在理工的領域：理論物理和電機。爲使資料詳實，這六個研究生都有豐富的研究經驗，其中兩人有多達七年的博士班研究經歷，稍短的兩位研究生也有四年的博士班的作研究經驗。

資料收集爲兩階段的訪談，第一階段的訪談主題爲科學知識的本質，其討論的綱要依次爲：觀察、研究過程、數據、研究結果、知識內涵、和知識的發展；第二階段的訪談主題爲研究知識的建構，配合研究知識的建構過程中，一些理論、哲學、價值、方法、及實際應用等子題，並關切這些子題的相互關係。

本研究的結果發現，研究生對於不同的議題採取不同的立場，因此他們對科學知識的態度並不一致；此外研究生於討論知識的本質時，較能接受建構哲學的觀點，但在他們實際從事研究工作時，則相當堅持實證哲學的規範。

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A Model of the Formation of Preservice Teachers' Perspectives on Science Teaching

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ABSTRACT

This study proposes a model to illustrate the relationship between preservice teachers' academic achievements and their perspectives on science teaching. This model involves two intermediate variables of the understanding of the nature of science and attitudes toward science. A survey was conducted to test the goodness of fit of the model. 428 preservice teachers were sampled in a Teachers College in Taipei. The model was confirmed by the data collected with an explanatory power of 29.81%. The data in this study supported the significant role of the understanding of the nature of science and attitudes toward science in the formation of desirable perspectives on science teaching. It was also found that courses offered by the Teachers College were not sufficient to promote adequate understanding of the nature of science, positive attitudes toward science, and desirable perspectives on science teaching.

Key words: teacher education, the understanding of the nature of science, attitudes toward science

I. Introduction

Regarding the knowledge base of teachers, it has long been accepted that subject matter knowledge, educational knowledge, and a general base in the liberal arts are the three main elements essential for a school teacher. Although there is strong disagreement on how much weight each individual element carries, it is hard to conclusively deny the contribution any one of them may make. To arrange a suitable time-table of a teacher education curriculum, however, there is a need for theoretical explanations or models which may formulate how teachers' knowledge affects and shapes their perspectives on teaching and teaching behavior. The explanations or models may also be used to assess a teacher education program and give advice on the allocation of appropriate course share for the three main elements in the limited time scope of the period of teacher preparation.

1. The model

To illustrate the relationship between teachers' knowledge and perspectives on science teaching, the author proposes a model in the current study. The model involves two intermediate components, teachers' understanding of the nature of science and attitudes toward science, between teachers' knowledge and perspectives on science teaching, through which, the author is convinced, the teachers' knowledge exerts its major effect on their perspectives on science teaching and so on teaching behavior. The model is shown in Figure 1.

The model emphasizes the critical role of teachers' understanding of the nature of science and attitudes toward science in the formation of their perspectives on science teaching. In addition to directly affecting and shaping their perspectives

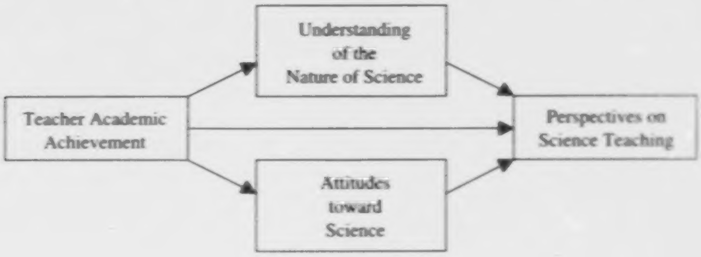
Understanding of the Nature of Science
Teacher Academic Achievement
Perspectives on Science Teaching
Attitudes toward Science

Fig. 1. The model.

on science teaching, the major effect of teachers' knowledge may, however, be to advance their understanding of the nature of science and attitudes toward science. It is suggested a teacher education program should be able to develop desirable perspectives on science teaching as well as promote teachers' understanding of the nature of science and attitudes toward science. Otherwise, the poor performance of the understanding of the nature of science and attitudes toward science obstruct the formation of desirable perspectives on science teaching.

The development of an adequate understanding of the nature of science has been convincingly advocated as a desired outcome of science education by science educators and institutions (American Association for the Advancement of Science [AAAS], 1989; Martin, 1972; National Science Teachers Association [NSTA], 1982; Robinson, 1968). It has been argued that, in order to achieve adequate understanding of the nature of science in students, teachers of science should themselves possess an adequate understanding of the nature of science (Miller, 1963; Billeh and Hasan, 1975; King, 1991).

Robinson (1969) proposed that a teachers' understanding of the nature of science is a critical force in shaping his classroom behavior in three aspects: oral instruction, pupil task selection, and the selection of instructional materials. Science teachers with an adequate understanding of the nature of science, he argued, would make their explanations reflect scientific terms as constructs, not real things, select pupil tasks likely to serve a function of inquiry, and not verification, and choose materials with revisionary characteristics of science.

The link between teachers' understanding of the nature of science and their teaching behavior has been confirmed by many others. Smith and Anderson (1984) found that a science teacher committed to a belief that scientific theories could be inferred from observation anticipated that his students could discover photosynthesis by observing the growth of plants. Lantz and Kass (1987) reported on three high school chemistry teachers, with differences in the understanding of the nature of science, who taught the same chemistry curriculum in very different ways. Duschl and Wright (1989) indicated that science teachers convinced of a hypothetico-deductive view of the scientific method, paid little attention to the nature and role of theories in making curricular and instructional decisions. There are other studies which confirm this link (Brickhouse, 1990; Gallagher, 1991; King, 1991).

Since Krathwohl, Bloom, and Masia developed the taxonomy of the affected domain, research of attitudes has received special attention from educators (Wareing, 1982). The development of positive attitudes toward science, likewise, has been accepted as one of the major aims of science education (Gardner, 1975).

Teachers' attitudes toward science are studied because of their perceived importance in science teaching. Elementary teachers' instructional behavior has been shown to be influenced by their attitudes toward science. Taiwo (1981) investigated the degree of the relationship between attitudes scores, measured by his own instrument, and the practical teaching scores of one hundred and twenty preservice science teachers and found a high relation between the two. He concluded that "attitude scores as measures of attitudes toward science teaching are significant predictors of practice teaching performance." (p. 489) In a previous study, Sunal (1980) reported a similar result.

In an attempt to establish a theoretical foundation for the study of attitudes toward science in science teacher education, Koballa and Crawley

(1980) suggested attitudes toward science:

(1) serve as a convenient, evaluative summary of a wide variety of beliefs about science,

(2) express important aspects of one's personality,

(3) serve a function of knowledge, and

(4) serve a utilitarian function.

They argued that the term "attitudes toward science" should be used to refer to a general and enduring positive or negative feeling about science and that a teacher's attitudes toward science are reflected in his teaching practices.

From the typical behaviorist point of view, there would be a direct effect of knowledge, which teachers acquire from the courses taken in their teacher education, on teaching behavior (Di Vesta, 1989). This view excludes any possible indirect components between teachers' knowledge and their teaching behavior, and regards the intermediate process as a "black box". Many studies have revealed that the way a teacher's professional abilities develop is not so simple or straightforward (Elbaz, 1991; Duffee and Aikenhead, 1992).

Schön rejected the traditional thought of "Technical Rationality", where teachers' knowledge can powerfully shape their teaching behavior and lead to predictability and control in practical affairs. Rather, he suggested, the theory that actually governs one's actions is his theory-in-use (Schön, 1983). Personal perspectives on science teaching are a theory-in-use. They are formed not only by knowledge acquired from teacher education programs, but also personal beliefs, previous experience in the classrooms, etc. Personal perspectives on science teaching may not only act as "Intuitive Screens", through which one may interpret teaching practice, but also are affected and modified by the "psycho-social dynamics" of teaching practice (Goodman, 1988).

The understanding of the nature of science and attitudes toward science are personal beliefs and affection. Although it's significance for science teaching is evident, unfortunately, they are not included in formal teacher education and develop casually from the "hidden curriculum". The model, proposed in this study, advocates their important role and suggests they be one of the main goals of the teacher education program. The objective of this study is to conduct an empirical survey to test the fitness of the model to the data collected, and accordingly make suggestions for improving the implementation of science teacher education.

II. Methods

The study aims to test the model proposed by the author. Basically, this is a correlational survey. Data collected will be used to justify the model and clarify the relationships between the various components of the model.

1. Sample

The data are based on a sample of 428 preservice elementary teachers, including the Department of Elementary Education and the Department of Mathematics and Science Education, ranging from freshmen to seniors, at a Teachers College in Taiwan.

2. Variables

In the study, teachers' knowledge as independent variables is delineated by preservice teachers' academic achievements, which are classified into three catagories, general liberal arts, educational knowledge, and subject matter knowledge, while each category contains two variables, credit hours taken and GPA earned. Both the understanding of the nature of science and attitudes toward science are intermediate variables, dependent variables to academic variables and independent variables to perspectives on science teaching at the same time. Intermediate variables may mediate the effect of academic variables on the perspectives on science teaching and exert their own effect on that as well. Perspectives of science teaching are the dependent variable to preservice teachers' academic achievement, understanding of the nature of science and attitudes toward science.

Preservice teachers' perspectives on science teaching, understanding of the nature of science and attitudes toward science are measured by the three instruments, Perspectives of Science Teaching (POST), Understanding of the Nature of Science (UNOS), and Attitudes toward Science (ATS), respectively. Data on academic achievement was obtained directly from the registration office of the Teachers College.

3. Instruments

The three instruments are all Likert type scale with four options. The POST contains 40 items in four subscales: Teacher & Teaching, Learner & Learning, Curriculum & Textbook, and Experiment & Scientific activity, with ten items in each subscale. Twenty items carry positive statements, while the other twenty items carry negative statements. To each statement subjects are asked to respond with one of the following four options, "strongly agree", "agree", "disagree", "strongly disagree". In order to avoid responses convergent to a neutral opinion, there is no "neutral" option.

The ATS was modified from a previous instrument. Fraser (1977, 1978) developed the Test of Science-Related Attitudes (TOSRA) attempting to measure attitudes toward science and scientific attitudes in a single instrument. The TOSRA carries seven subscales, (1) Social Implications of Science, (2) Normality of Scientists, (3) Attitude Toward Scientific Inquiry, (4) Adoption of Scientific Attitudes, (5) Enjoyment of Science Lessons, (6) Leisure Interest in Science, and (7) Career Interest in Science. The subscales (1), (2), (5), (6), and (7) are designed for measuring attitudes toward science and the other two for scientific attitudes. Satisfactory reliability and validity has been reported in high school students and teachers (Fraser, 1978; Schibeci, 1981).

TOSRA's subscales (1), (5), (6), and (7) make up the ATS in this study. The ATS, therefore, carries 40 items in four subscales: Social Implications of Science, Enjoyment of Science Lessons, Leisure Interest in Science, and Career Interest in Science, with ten items in each subscale. The ATS has half the items as positive statements and the other half as negative statements.

Many instruments for measuring the understanding of the nature of science have been reviewed, such as the Test on Understanding Science (TOUS) (Klopfer and Cooley, 1963), Wisconsin Inventory of Science Processes (WISP) (Scientific Literacy Center, 1967), Nature of Science Scale (NOSS) (Kimball, 1967), Science Process Inventory (SPI) (Welch, Wayne and Pella, 1968), Inventory of Views on the Nature of Science (IVNS) (Durkee, 1975),and the Nature of Scientific Knowledge Scale (NSKS) (Rubba and Andersen, 1978). They have made significant contributions to the development of the Understanding of the Nature of Science (UNOS) instrument in this study.

Traditional debate on the nature of science among philosophers of science centers on the relationship between outcome (scientific knowledge) and process (scientific method). Post-Kuhnian philosophers of science, adopting a historical and socio-psychological approach, have suggested the scientific community is a collective representation of science. Therefore, three subscales reflecting the three aspects of science are included in the UNOS. They are Nature of Scientific Method (14 items), Nature of Scientific Knowledge (22 items), and Nature of Scientific Enterprise (16 items). The item form and response format of the UNOS is the same as the POST and ATS instruments.

In the previous pilot study, the reliabilities and validities of the instruments were drawn. The internal consistency reliability was calculated using the Cronbach a coefficient, 0.81, 0.80, and 0.95 for the Perspectives of Science Teaching (POST), the Understanding of the Nature of Science (UNOS), and the Attitudes toward Science (ATS), respectively. In the current study, the Cronbach a coefficients are 0.76, 0.71, and 0.95, respectively.

Discriminant validity, developed by Block (1963), was evident with ATS. Block suggested that when the value of subscale intercorrelation was smaller than the square root of the product of the corresponding subscale reliability, it represented a perfect conceptual equivalence. Since the ATS subscale intercorrelations (values of 0.47 [I×II], 0.37 [I×III], 0.37 [I×IV], 0.78 [II×III], 0.81 [II×III], and 0.77 [III×IV]), according to the pilot study, were smaller than the square root of the product of the corresponding subscale reliability, it was considered justifiable to maintain all four ATS subscales as separate dimensions. The discriminant validity of the ATS remains evident in the current study, since its subscale intercorrelations (values of 0.42 [I×II], 0.35 [I×III], 0.37 [I×IV], 0.77 [II×III], 0.74 [II×IV], and 0.74 [III×IV]) are smaller than the square root of the product of the corresponding subscale reliabilities. The reliability of ATS and its subscales for the pilot study and the current study is shown in Table 1.

The Discriminant validity of the UNOS and POST does not hold, indicating that concept of the nature of science and perspectives on science teaching, respectively, might be structures not easily devided into parts. However, concerns about content validity of the ATS, UNOS, and POST were emphasized during the whole process of instrument development. The relevance and appropriateness of each item in the instruments was scrutinized by philosophers of science, science educators, faculty members of the teachers college, and students of the teachers college. These efforts were made to improve the content validity of the ATS, UNOS, and POST.

Table 1. Reliability of the attitudes toward science (ATS) in the pilot study and the current study.

Scale	No. of Items	a coefficient Pilot Study	Current Study
Social Implications of Science (Subscale I)	10	0.77	0.80
Enjoyment of Science Lessons (Subscale II)	10	0.92	0.91
Leisure Interest in Science (Subscale III)	10	0.86	0.85
Career Interest in Science (Subscale IV)	10	0.92	0.91
Total	40	0.95	0.95

Table 2. Correlation coefficients of correlates with scores on the POST, UNOS, and ATS

Correlate	POST	UNOS	ATS
UNOS	.51**	—	.11*
ATS	.14**	.11*	—
CRLA	.0802	-.0848	-.0586
GPALA	.1892**	.1106*	-.0586
CRSCI	.0438	-.0041	.1479**
CPASCI	.1067*	.1655**	.1224*
CRED	.0681	-.1572**	-.1744**
GPAED	.2355**	.0938	-.1127*

CRLA---Credit Hours in Liberal Arts
GPALA---GPA in Liberal Arts
CRSCI---Credit Hours in Sciences
GPASCI---GPA in Science
CRED---Credit Hours in Education
GPAED---GPA in Education
*P < 0.05 **P < 0.01

4. Data analysis

Analyses of data collected were performed by employing the SPSS package at the Weeg Computer Center at the University of Iowa. The statistical method of this study included the following steps:

(1) The Pearson Correlation was used to analyze the correlations between preservice teachers' academic achievements, including credit hours taken in liberal arts, GPA in liberal arts, credit hours taken in sciences, GPA in sciences, credit hours taken in education, and GPA in education, and scores of the POST, UNOS, and ATS. The intercorrelation of POST, UNOS, and ATS was also assessed.

(2) Multiple regression was employed to investigate the relative effect of academic achievements on the scores of the POST, UNOS, and ATS.

(3) Chi-Square (X^2) was used to test the fitness of the model for the data collected..

III. Results

1. Correlations

Several correlations both positive and negative, were found between academic achievement, POST, UNOS, and ATS. There are shown on Table 2.

2. Multiple Regression Results

A series of stepwise multiple regression analyses were employed on three regression models: dependent variable POST with independent variables credit hours in liberal arts (CRLA), GPA in liberal arts (GPALA), credit hours in sciences CRSCI), GPA in science (GPASCI), credit hours in education (CRED), GPA in education (GPAED), ATS, UNOS; dependent variables UNOS and ATS with independent variables credit hours in liberal arts (CRLA), GPA in liberal arts (GPALA), credit hours in sciences (CRSCI), GPA in science (GPASCI), credit hours in education (CRED), GPA in education (GPAED). In the regression analyses, only independent variables with $P < 0.05$ are reported.

In Table 3, four independent variables, UNOS, GPAPE, ATS, CRPE, meet the 0.05 significance level and account for 29.81% of the variance. The UNOS scores alone account for 24.77% of the variance whereas the other three account for approximately 5%. In Table 4, GPASCI and CRPE meet the 0.05 significance level and account for a total of 4.3% of the variance. With ATS as a dependent variable, CRPE, CRSCI, GPASCI, and GPAPE meet the 0.05 significance level and account for a total of 12.51% of the variance (Table 5). CRSCI and GPASCI account for 7.44%, while CRPE and GPAPE held a negative standardized partial regression coefficient --path coefficient--(Beta). The path coefficient is an indi-

Table 3. Setp-wise Regression Analysee* between the Independent Variables Credit Hours in Liberal Arts (CRLA), GPA in Liberal Arts (GPALA), Credit Hours in Sciences (CRSCI), GPA in Science (GPASCI), Credit Hours in Education (CRED), GPA in Education (GPAED), ATS, UNOS, and the Dependent Variable, POST, for Preservice Elementary Teachers

	Beta				R^2	Significance
	UNOS	GPAED	ATS	CRED		
Step 1	.4977				.2477	0.0000
Step 2	.4775	.1807			.2799	0.0005
Step 3	.4641	.1948	.1169		.2875	0.0029
Step 4	.4269	.1619	.1335	.1191	.2981	0.0136

*Only the independent variables with $P < 0.05$ are reported

Table 4. Setp-wise Regression Analysee* between the Independent Variables Credit Hours in Liberal Arts (CRLA), GPA in Liberal Arts (GPALA), Credit Hours in Sciences (CRSCI), GPA in Science (GPASCI), Credit Hours in Education (CRED), GPA in Education (GPAED), ATS, UNOS, and the Dependent Variable, POST, for Preservice Elementary Teachers

	Beta		R^2	Significance
	GPAED	CRED		
Step 1	.1655		.0274	0.0009
Step 2	.1384	-.1278	.0430	0.0112

*Only the independent variables with $P < 0.05$ are reported

cator of weight of affecting variables toward the affected ones, the higher the path coefficient, the more the power of influence of the affecting variable.

3. The Model

Figure 2 shows a path diagram with significant path coefficients, indicated in Tables 3, 4, and 5, showing the relationships between POST, UNOS, ATS, and academic variables of preservice elementary teachers in this study. The initial regression model (Figure 1), therefore, was trimmed down to a final model (Figure 2), containing only the significant independent variables.

Table 5. Setp-wise Regression Analysee* between the Independent Variables Credit Hours in Liberal Arts (CRLA), GPA in Liberal Arts (GPALA), Credit Hours in Sciences (CRSCI), GPA in Science (GPASCI), Credit Hours in Education (CRED), GPA in Education (GPAED), ATS, UNOS, and the Dependent Variable, POST, for Preservice Elementary Teachers

	Beta				R^2	Significance
	CRED	CRSCI	GPASCI	GPAED		
Step 1	-.1744				.0304	0.0005
Step 2	-.2923	.2738			.0915	0.0000
Step 3	-.2733	.2879	.1188		.1048	0.0002
Step 4	-.2019	.2927	.2159	-.1791	.1251	0.0027

*Only the independent variables with $P < 0.05$ are reported

The measure of goodness of fit for the final model was performed in accordance with Pedhazur (1982). It is a ratio (Q) between the initial multiple R^2 value and final multiple R^2 value, which ranges between zero and one, with the larger the ratio the better the fit of the data for the model. The goodness of fit (Q) is calculated by:

$$(Q) = (1-R^2m)/(1-M)$$

R^2m is equal to $1-(1-R_1^2)(1-R_2^2)(1-R_3^2)...(1-R_P^2)$ in the initial model and M is equal to $1-(1-R_1^2)(1-R_2^2)(1-R_3^2)...(1-R_P^2)$ in the final model. For large samples, the measure of goodness of fit, Q, can be tested for significance as follows:

$$W = -(N-d)\log_e Q$$
$$= -(N-d)\log_e[(1-R^2m)/(1-M)]$$

where N=sample size; d=number of overidentifying restrictions; and $\log_e$ = natural logarithm. W has an approximate X^2 distribution with df=d.

The initial and final multiple R^2 values are shown in Table 6. The W (X^2) values for preservice elementary teachers is 15.145 with 10 df. It is therefore concluded that the model does fit the data collected in this study. Their explanatory power is 29.81%.

A numerically relative weight of teachers' academic variables, the understanding of the nature of science, and attitudes toward science, derived from Figure 2, may make a more clear comparision. It is shown in Table 7.

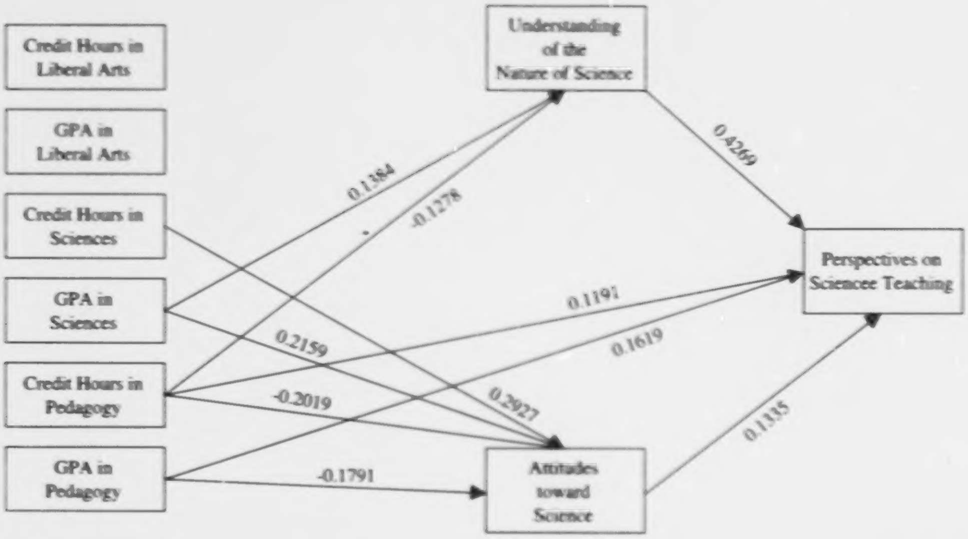
Credit Hours in Liberal Arts
GPA in Liberal Arts
Credit Hours in Sciences
GPA in Sciences
Credit Hours in Pedagogy
GPA in Pedagogy
Understanding of the Nature of Science
Perspectives on Sciencee Teaching
Attitudes toward Science
0.1384
-0.1278
0.4269
0.1191
0.1619
0.2159
-0.2019
0.2927
0.1335
-0.1791

Fig. 2. Path diagram of academic variables, understanding of the nature of science, and attitudes toward science on preservice teachers' perspectives on science teaching

Table 6. Initial and final multiple R^2 for paths

Path To	Initial MultipleR^2	Final Multiple R^2
Total Preservice elementary Teachers		
Perspectives on Science Teaching	0.31	0.30
Understanding of the Nature of Science	0.06	0.04
Atitudes toward Science	0.13	0.13

IV. Discussion

The model in this study was an attempt to advocate the importance of science teachers' understanding of the nature and attitudes toward science in the formation of their perspectives on science teaching. The data collected in this study confirmed the model. The effect of the understanding of the nature of science on the perspectives on science teaching holds the highest path coefficient, indicating it is the main factor in this model. Teachers' attitudes toward science also have a moderate effect in this model. The outstanding performance of the two confirms previous research reviewed in the introduction to this paper.

Compared to the understanding of the nature of science and attitudes toward science, the individual category of teachers' academic achievement has less effect on the formation of perspectives on science teaching. There are only two variables, credit hours taken in education and GPA in education, with a direct and moderate effect. This comparison suffices to remind science educators of the lack of emphasis and formal courses for them in the most science teacher education programs. To promote preservice teachers' understanding of the nature of science, many have suggested the study of the history and philosophy of science be effective courses (Abimbola, 1983; Duschl, 1985; Matthews, 1988; Robinson, 1969). To foster positive attitudes toward science among preservice teachers, Huang (1991) reported that Science-Technology-Society (STS) oriented science teaching was particularly effective.

Preservice teachers' educational achievements have a positively direct effect on the perspectives on science teaching, but a negative effect on both the understanding of the nature of science and attitudes toward science. This reveals a hint of weakness in course arrangement in the Teachers College. Most courses associated with education or school learning and teaching are offered by faculty members from the Department of Elementary Education. Science educators in the Depart-

Table 7. Overall effect of teachers' knowledge, understanding of the nature of science, and attitudes toward science on perspectives on science teaching

Affecting Variable	Affected Vaiable	Weight of Effect
	The Perspectives on Science Teaching	
The Understanding of the Nature of Science		.4269
Attitudes toward Science		.1335
Academic Achievement		.3026
Liberal Arts		.00
Science	.1384×.4269+.2927×.1335+ .2159×.1335=	.1270
Education	0.1191+.1619-(.1278×.4269+ .2019×.1335+.1791×.1335)=	.1756
	The Understanding of the Nature of Science	
Academic Achievement		.0106
Liberal Arts		.00
Science		.1384
Education		-.1278
	Attitudes Toward Science	
Academic Achievement		.1276
Liberal Arts		.00
Science	.2927+.2129=	.5086
Education	-.2019+-.1791=	-.3810

ment of Mathematics and Science Education offer limited science education courses. Faculty members in elementary education are experts in education but most do not have any exposure to science from their undergraduate years on. It is very likely that an incomplete or distorted image of science and science education is thus brought into preservice teachers' classrooms, where their understanding of the nature of science and attitudes toward science suffer. Current advocates of pedagogical content knowledge, calling for science educators who are educational experts in a particular science subject, may help shed light on this problem. A reasonable reallocation of the division of labor between educators in elementary education department and science educators in science education department is suggested.

Science courses have a positive effect on the understanding of the nature of science and attitudes toward science. Their overall effect on them, however, is as little as 2.74% and 7.43%, respectively. The science courses in the Teachers College normally have typical lectures with occasional recipe-type laboratory work. Often, massive amounts of content has to be taught in a limited amount of time. Science, thus, is represented as a body of knowledge with fragments of scientific knowledge and isolated vocabulary and mathematical formula. Perhaps scientific knowledge, more or less, is learned, but there is, however, little opportunity to develop a complete appreciation of science. Science is not only a body of knowledge, but also a way of knowing (Moore, 1993). Activity-oriented or hands-on science courses, which may help understand the nature of science and foster positive attitudes toward science, are totally absent from the Teachers College. It is suggested they be included in the teacher education program.

There is no significant correlation between achievement in liberal arts and the performance of teachers' understanding of the nature of science, attitudes toward science, or perspectives on science teaching. This shows a likely flaw in the strict policy of liberal arts education in the Teachers College and other undergraduate education programs in Taiwan. Under the title of liberal arts in this study are courses like history, geography, philosophy, etc. They are a group of required courses for all undergraduate students in Taiwan on the order of Ministry of Education. The objectives and value of liberal arts is apparently indispensable. The implementation, however, should be flexible and suitable to the function and objectives of the individual program. In the Teachers College, its main constitutional objective is to foster effective science teachers. The history and philosophy of science would be more suitable for science teacher education programs than general history and philosophy because the objectives and function of both liberal arts education and teacher education can be covered in the same course.

The model was confirmed in this study, indicating the significant role of the understanding of the nature of science and attitudes toward science in the formation of desirable perspectives on science teaching. However, its explanatory power is only 29.81%. That means all courses offered by the Teachers College can only account for not more than one third of the variance. More different variables or courses should be identified and added to the course options in the Teachers College.

V. Recommendations

Based on the data collected, analysis of data, and discussion in this study, a number of recommendations for science teacher education are made in conclusion.

Teachers' understanding of the nature of science and attitudes toward science have to be stressed in the formal curriculum instead of in the hidden curriculum. A number of topics thought to be able to promote them, such as the history and philosophy of science and STS oriented science, should be added to the teacher education program.

Educational courses offered by faculty members from elementary education departments apparently successfully foster preservice teachers' perspectives on science teaching to a certain degree, but do not work well in promoting their understanding of the nature of science and attitudes toward science. This should be the job of science educators. Some educational courses have to be offered by science educators in science education programs instead of faculty members in elementary education departments.

Science classes in a typical lecture-style with some recipe-type experiments have little effect on the teachers' understanding of the nature of science, attitudes toward science, and perspectives on science teaching. Activity-oriented or hands-on science courses should be included.

A flexible policy of liberal arts education should apply. Individual programs should be empowered to offer appropriate courses to meet their objectives and functions.

References

Abimbola, I. O. (1983). The relevance of the "new" philosophy of science for the science curriculum. *School Science & Mathematics*, **83**(3), 181-193.

American Association for the Advancement of science (AAAS).(1989). *Science for All Americans*. New York: Oxford University Press.

Billeh, V. Y.and Hasan, O. E. (1975). Factors affecting teachers' gain in understanding the nature of science. *Journal of Research in Science Teaching*, **12**(3), 209-219.

Block, J. (1963). The equivalence of measures and the correction for attenuation. *Psychological Bulletin*, **60**(2), 152-156.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*. May-June, **41**(3), 53-62.

Di Vesta, F. J. (1989). Applications of cognitive psychology to education. In M. C. Wittrock and F. Farley (eds.) *The Future of Educational Psychology*, 37-73.

Duffee, L.and Aikenhead, G. (1992). Curriculum change, student evaluation, and teacher practical knowledge. *Science Education*, **76**(5): 493-506.

Durkee, G. P. (1975). *An inventory of views on the nature of science among college science faculty*. Unpublished doctoral dissertation, The University of Iowa.

Duschl, R. A. (1985). Science education and philosophy of science twenty-five years mutually exclusive development. *School Science and Mathematics*, **85**(7), November, 541-555.

Duschl, R. A. and Wright, E. (1989). A case study of high school teachers' decision-making models for planning and teaching science. *Journal of Research in Science Teaching*, **26**, 467-502.

Elbaz, F. (1991). Research on teacher's knowledge: the evolution of a discourse. *Journal of Curriculum Studies*, **23**(1), 1-19.

Fraser, B. J. (1977). Selection and Validation of attitude scales for curriculum evaluation. *Science Education*, **61**(3): 317-329.

Fraser, B. J. (1978). Development of a test of Science-related attitudes. *Science Education*, **62**(4): 509-515.

Gallagher, J. J.,(1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education*, **75**(1): 121-133.

Gardener, P. L. (1972). Attitudes toward physics: personal and enviromental influence. *Journal of Research in Science Teaching*, **13**, 111-125.

Gardner, P. L. (1975). Attitudes to science: A review. Studies in Science Education, **2**, 1-41

Goodman, J. (1988). Constructing a practical philosophy of teaching: a study of preservice teachers' professional perspectives. *Teaching & Teacher Education*, **4**(2), 121-137.

Huang, D. S. (1991). *A Study of the Effectiveness of a College Biology Course*. Unpublished doctoral dissertation, The University of Iowa.

Kimball, M. E. (1967). Understanding the nature of science: A comparison of scientists and science teachers. *Journal of Research in Science Teaching*, Vol. 5, 110-120.

King, B. B. (1991). Beginning teachers' knowledge of and attitude toward history and philosophy of science. *Science Education*, **75**(1): 135-141.

Klopfer, L. E.and Cooley, W. W. (1963). *Test on understanding science*, Form W. Princeton: Educational Testing Service.

Koballa, Jr. T. R.and Crawley, F. E. (1985). The influence of attitude on science teaching and learning. *School Science and Mathematics*, Mar. **85**(3), 223-232.

Lantz, O.and Kass, H. (1987). Chemistry teachers' function paradigms. *Science Education*, **71**(1), 117-134. ,

Martin, M. (1972). *Concepts of Science Education: A philosophical Analysis*. Lanham, MD: University Press of America, Inc.

Matthews, M. R. (1988). A role for history and philosophy in science teaching. *Educational Philosophy and Theory*, **20**(2), 67-81.

Miller, P. E. (1963). A comparison of the abilities of secondary teachers and students of biology to understand science. *Iowa Academy of Science*, **70**, 510-513.

Moore, J. A. (1993). *Science as a Way of Knowing: The Foundations of Modern Biology*. Cambridge: Harvard University Press.

National Science Teachers Association (NSTA), (1982). Recommended standards for the preparation and certification of secondary school teachers of science. *The Science Teacher*, December, 57-62.

Pedhazur, J. E. (1982). *Multiple Regression in Behavioral Research Explanation and Prediction*. New York, NY: Holt, Rinehart and Winston.

Robinson, J. T. (1968). *The Nature of Science and Science Teaching*. Belmont, CA: Wadsworth Publishing Company, Inc..

Robinson, J. T. (1969). Philosophy of science: implications for teacher education. *Journal of Research in Science Teaching*, **6**, 99-104.

Rubba, P. A.and Andersen, H. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education*, **62**(4): 449-458.

Schibeci, R. A. (1981). Science teachers and science-related attitudes. *European Journal of Science Education*, **3**(4), 451-459.

Schön, D. A. (1983). *The reflective practitioner: How Professionals Think in Action*. New York: Basic Books.

Scientific Literacy Center, (1967). *Wisconsin Inventory of Science Processes*. Madison, Wisconsin: The Regents of the University of Wisconsin.

Smith, E. L.and Anderson, C. W. (1984). Plants as producers: A case study of elementary science teaching. *Journal of Research in Science Teaching*, **21**(7), 685-698.

Sunal, D. W. (1980). Effect of field experience during elementary methods courses on preservice teacher behavior. *Journal of Research in Science Teaching*, **17**, 17-23.

Taiwo, D. (1981). Attitude scores as determinants of practice teaching performances of preservice undergraduate science teachers. *Science Education*, **65**(5): 485-492.

Wareing, C. (1981). Cognitive style and developing scientific sttitudes in the SCIS classroom *Journal of Research in Science Teaching*, **18**, 137-143.

Welch, W. W.; Wayne, W.and Pella, M. O. (1968). The development of an instrument for inventorying knowledge of the processes of science. *Journal of Research in Science Teaching*, **5**, 64-68.

職前教師教學觀點形成的模式

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摘　要

本文提出一個模式說明職前敎師的學業成就和科學敎學觀的關係。這個模式包含兩個中間變項，對科學本質的了解和對科學的態度。本研究應用一調查研究來檢驗這個模式是否適合所蒐集的數據，共計蒐集428位台北某一師範學院學生爲樣本。所蒐集到的數據支持此模式，且此模式具有29.81％的解釋力。所蒐集到的數據同樣的支持職前敎師對科學本質的了解和對科學的態度，在形成科學敎學觀中佔有重要的地位。本研究發現此師院所提供的修業科目不能有效的促進職前敎師對科學本質的了解和對科學的態度和科學敎學觀。

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Application of Neural Network for Implementing a Practical Student Model

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ABSTRACT

The student model plays a critical role in intelligent tutoring systems. With a student model, the tutoring system can adapt the learning process in order to satisfy the individual needs of every student. Here we use neural network methods to implement the student model. In the proposed approach, first a teacher has to apply the curriculum structure and crucial pedagogical steps for the learning process. These two data will be transmitted as proper weights and layers in the network. Then our neural network takes the student's responses as input data and performs learning. During learning, the network records the student's history and changes the corresponding weights in order to record his or her learning state. Finally, the system infers the student's misunderstandings and provides suggestions to the tutor. Our goal is to make a student model embedded in a neural network, and evaluate misunderstandings in the learning processes of learners. Based on the experiment, the proposed neural network can infer the topic where the student's understanding is weakest as a reference for the next lesson.

Key words: student model, intelligent tutoring system, neural network, pedagogical step, learning topics.

I. Introduction

Intelligent Tutoring System (ITS) consists of four modules: domain expert module, tutoring module, interface module, and student model. The domain expert module simulates a human expert in teaching student or solving problems. The tutoring module is a set of specifications of what instructional material to present and how and when the material should be presented. The interface module provides the student with uniform access to the components of the ITS. The student model represents the student's current state of knowledge. From the student model, the tutoring system can assess the student's mastery of the instructional material, record his or her learning progress, and then select the proper explanation level for the student. Due to the importance of student model, much previous research addressed this problem. Based on previous research, the four types of student models are as follows:

1. *Performance measure* (Stansfield et al., 1976). This records the student's test scores. It does not point out what knowledge has been acquired, only an assessment of "how much" knowledge has been acquired.
2. *Overlay models* (Brown et al., 1973, 1982; Burton & Brown, 1979; Carbonell, 1970; Carr, 1977; White & Frederiksen, 1985). This type of student model assumes that the student's knowledge is a subset of the expert's. It generates problems how to represent the student's

knowlege which is different from the expert's.

3. *Buggy models* (Brown & Burton, 1978; Burton, 1982; Sleeman & Smith, 1981; Stevens & Collins, 1977; VanLehn, 1987). In this model, student knowledge is represented as a set of bugs or misconceptions. This requires a bug library that is relatively difficult to build for a complex domain.
4. *Simulations* (Stevens et al., 1983; Wenger, 1987). By analyzing the student's behavior, an executable model is constructed to imitate student knowledge.

A difficulty lies in, for example, the construction of correct rules and mal-rules for simulating the student's learning. Although, there are different concerning problems for each model, two general difficulties must be dealt with in any of the above student models. The difficulties are as follows:

1. *Rules' construction.* Most student models are built with rules using an artificial intelligence technique. Because of the problem of verifying rule correctness and completeness, construction of rules is difficult.
2. *Efforts toward ideal student models.* It is difficult to build an ideal student model using the current techniques. Self (1990) has suggested that an ideal student model may be overwhelmed by difficult problems.

Several approaches to making student modeling more tractable have been developed in recent years. Examples of less precision-oriented modeling approaches include bounded student models (Elsom-Cook, 1989) and granularity-based recognition of students' problem-solving plans and strategies (e.g., Greer et al, 1989). These approaches demonstrate that student models need not be precise and accurate. After consulting these methods, a "practical student model" has to be implemented to record the student's learning process, and to infer his or her knowledge state so as to provide information about what concepts must be enhanced. Thus we think that the practical student model may be more easily implemented in an ITS than the ideal student model. A practical student model can avoid the second difficulty above. In this paper, we wish to use a neural network to implement a practical student model because neural networks have the following traits:

1. *Non-algorithmic computing.* In the neural network, the computation proceeds in accordance with pattern learning and recalling. During the learning process, the neural network can adapt its weights repeatedly to achieve learning goals. In the recalling process, information will be retrieved from the neural network. Hence, we need not write a sequence of rules as mentioned in the first difficulty above.
2. Learning and adaptation capacity. Learning ability is an important trait of neural networks and it is not achievable with conventional algorithms. When the neural network receives input data, its weights will record features of the data. This is similar to the changeability of a student's learning process.

In the proposed approach, a teacher first has to apply the curriculum structure and crucial pedagogical steps for the learning process. These two data will be transmitted as proper weights and layers in the neural network. Then the neural network takes the student's responses as input data and performs learning. During learning, the neural network records the student's history and changes the corresponding weights in order to record his or her learning state. Finally, the system infers the student's misunderstandings and provides suggestions to the tutor. Based on the experiment, the proposed neural network infers the weakest topic for next learning.

This paper is organized as follows. The basic concept of student learning is first described in the next section. Thereupon, the proposed student model using a neural network approach is introduced in Section III, and its detailed sub-networks are presented in Sections IV and V. To facilitate practical application of the proposed approach, we show the experimental results in Section VI. Finally, conclusions are discussed.

II. Pedagogical Steps and Learning Topics

An intelligent tutoring system aims at providing an interactive learning environment to students. On the basis of interactive sequences in the environment, the students can communicate with the tutoring system. These sequences are called "pedagogical steps". In other words, the tutoring system can use the pedagogical steps to retrieve the student's responses and then update the student model. The pedagogical steps are designed to involve some concepts in learning topics. Therefore, the relationship between pedagogical steps and learning topics can be constructed. These relationships are useful in evaluating the student's learning level. Consequently, we propose the pedagogical steps and the relationships as the fundamental data in designing our student model. The following introduces the definition and significance of these concepts.

Pedagogical steps. When a teacher designs a teaching process, the first consideration is pedagogical steps for each topic. During teaching, each student gets a different sequence of pedagogical steps and performs a particular action that may be responding yes or no, selecting items, filling in a blank or conversing with a teacher. From those responses, a teacher can judge the solution right or wrong. If the solution is right, it means that the student has a higher understanding degree. However, the student may fail to understand some learning topics. Therefore, if the student's response for every pedagogical step is recorded, the teacher can determine the level and deduce the student's weaknesses. Thus we need vital information concerning pedagogical steps for our design. The appendix lists all pedagogical steps for learning topics involving the subjects of "exponent and logarithm".

Learning topics. The curriculum structure is the learning topology for the curriculum. It is composed of several learning topics. For example, the learning curriculum and learning topics about the "exponent and logarithm" have a hierarchy as shown in Figure 1. The learning topics in the curriculum structure include "Exponent Definition", "Exponent-Property", "Logarithm Definition", "Relation of Exponent & Logarithm", and "Logarithm-Property". The learning topic j is denoted as C_j.

Relation between pedagogical steps and learning topics. A teacher has his or her own pedagogical steps for each learning topic in the teaching process. For example, if there is a pedagogical step $Step_i$ testing a key point of the learning topic C_j, we say that $Step_i$ is related to C_j. We can use a set representation to describe it as follows:

$$T(Step_i)=\{j|Step_i \text{ is related to } C_j\} \qquad \textbf{(1)}$$

Formula (1) means that the student may not understand the learning topics in $T(Step_i)$ if the student's response to $Step_i$ is not correct. Table 1 shows the relations $T(Step_i)$ for all i. An instance in the table is $T(Step_8)=\{2, 4, 5\}$.

A learning history is observed from the student's responses to pedagogical steps. For each learning topic, there is a corresponding learning performance recorded, and we define this as follows:

H_i: the learning history for the learning topic C_i.

III. Proposed Neural-based Model

In the proposed design, we first gather vital information when the user interacts with the system. Then we try to find the student's learning level and suggest the relational topic to enhance. Therefore, we propose the following structure to accomplish these tasks.

In our neural network as shown in Figure 2, there are two major subsystems: "history record" and "suggestion decision". They are stated as follows:

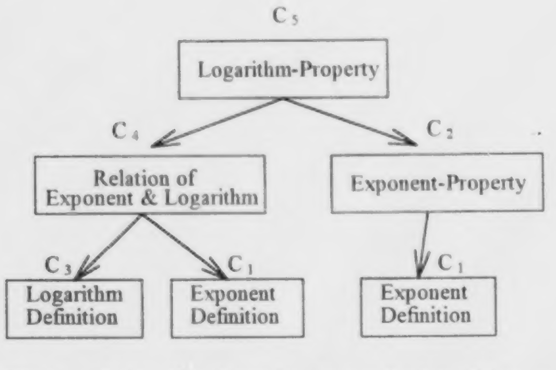

Fig. 1. A hierarchical tree for the curriculum of "exponents and logarithms" with index from C_1 to C_5.

Table 1. Relation between steps and topics.

i	$T(Step_i)$	i	$T(Step_i)$
1	{1}	6	{3}
2	{1,2}	7	{1,3,4}
3	{1,2}	8	{2,4,5}
4	{1,2}	9	{2,4,5}
5	{1,2}	10	{2,4,5}

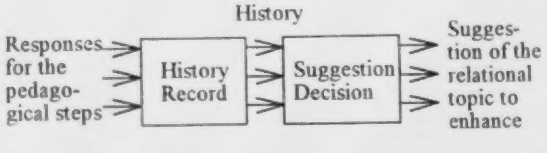
History
Responses for the pedagogical steps
History Record
Suggestion Decision
Suggestion of the relational topic to enhance

Fig. 2. Flowchart of student modeling in the proposed systems.

History record. When the student interacts with the learning environment, the first subsystem will record the student's responses to the pedagogical steps and continuously accumulate his or her learning history. In short, because the record of the student's learning history is constructed in this neural subsystem, we name it "History Record".

Suggestion decision. In this subsystem, the goal is to evaluate the student's learning level for giving a suggestion to the learner. Hence, the system can evaluate the student's learning level and decide which topic should be improved the next time.

The proposed neural network of three layers for our student model is pictured in Figure 3. The three layers are respectively the input layer, the hidden layer, and the output layer.

In the following sections we will introduce the definitions of all neurons and weights, initial values of weights, combining functions, transfer functions and adaptive algorithms in the network.

IV. History Record

Assume that the curriculum has m learning topics. For teaching these m topics, suppose that a tutor designs n pedagogical steps. Then the "History Record" neural structure has n input neurons representing pedagogical steps $Step_1$, $Step_2$, ..., $Step_n$, and m output neurons representing the learning history of learning topics H_1, H_2, ..., H_m.

4-1 Neuron definitions of $Step_i$ and H_i

First, let's define neurons in the input layer as follows..

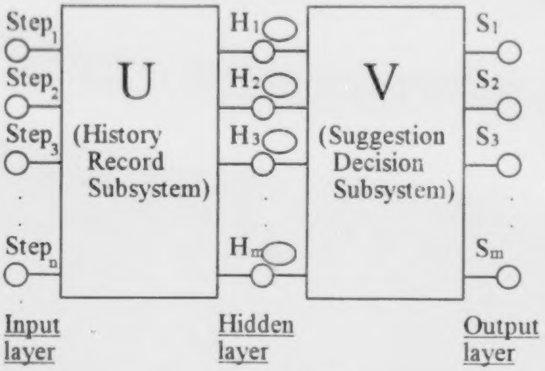

Fig. 3. The architecture of the proposed neural network for the student model.

$$Step_i = \begin{cases} +1 & \text{if a student makes an error response} \\ 0 & \text{if no corresponding response occurs} \\ -x & \text{if a student's is right} \end{cases}$$

where $x=|T(Step_i)|$ and $|T(Step_i)|$ is the number of learning topics related to the pedagogical step i.

$Step_i$ is the student's response for the ith pedagogical step. Now, let's take an example to illustrate the meaning of $Step_i$. Suppose that a tutor asks a student to use a testing problem as the sixth pedagogical step as given below.

Tutor: Please answer the following problem:
⇒ If $a>0$ and $a\neq 1$; $f(x)=\log_a(x)$, $f(x)$ is a function of an (1) exponent (2) logarithm?
Student:__

If the student incorrectly answers "exponent", the value of the sixth input neuron, $Step_6$, is equal to +1 because the learner has made an erroneous response. If the student correctly answers "logarithm", the value of $Step_6$ is equal to $-x$, where $x = |T(Step_6)|$. The "negative" here is used to represent the correctness of the student's performance. The value of x implies that the student understands the x relative concepts for the pedagogical step i.

Now, let's define the hidden layer or the output neurons of the history record subsystem. The neurons are denoted by H_1, H_2, ..., H_m. H_i stands for the learning history of a student for topic i. In the learning process, if a student behaves correctly for a certain concept, the corresponding neuron in the hidden layer will record his or her understanding level. Otherwise it represents the student's misunderstanding level. In other words, Hi represents the understanding level, misunderstanding level, or no obvious level for the learning topic i when $H_i < 0$, $H_i > 0$, or $H_i = 0$, respectively. The hidden layer stores a student's learning history. Using these stored data, the neural network can evaluate the student's learning state.

4-2 Connection matrix U

The connection matrix U in the "History Record" neural sub-network represents the relations defined in Formula (1) for all i. $u_{ij}=0$ means the pedagogical step i is not the crucial step of learning topic j or $j \notin T(Step_i)$. However, $u_{ij}\neq 0$ is for

$j \in T(Step_i)$ and means that there is a connection between input neuron $Step_i$ and neuron H_j in the hidden layer.

For each $u_{ij} \neq 0$, the initial value is calculated as follows.

$$u_{ij} = 1/x, \text{ where } x = |T(Step_i)| \quad \textbf{(2)}$$

Formula (2) is used to determine the initial value in accordance with the following fact: If the student encounters the learning topics for the first time, we may take the misunderstanding probabilities for these learning topics are equal. Therefore, for pedagogical step i of x related learning topics, the misunderstanding rate is $1/x$.

4-3 Combining functions and transfer functions

Since the neuron outputs of the hidden layer represent the learning history of the student, the student's responses for the pedagogical steps have to be accumulated in these neuron outputs. The self-connections of all neurons H_i are needed for this accumulation of the student's responses. The combining function $NetH_i$ of each neuron H_i is defined as follows:

$$NetH_i = H_i + \Sigma u_{ji} Step_j$$
$$\text{for all pedagogical steps } j \quad \textbf{(3)}$$

where H_i records the previous learning state for topic i.
The output of neuron H_i is defined as follows:

$$H_i = f(NetH_i) \quad \textbf{(4)}$$

and the transfer function f is defined as follows (or Figure 4):

$$f(y) = \begin{cases} 1 & \text{if } y > 1 \\ y & \text{if } 0 \leq y \leq 1; \\ -1 & \text{if } y < -1 \end{cases}$$

4-4 Adaptive algorithm

For the initial weights, $u_{ij} = 1/x$ for each i, j, of connection matrix U, we assume that the performances of misunderstanding the learning topics dominating by a pedagogical step are equal. However, this does not meet the practical cases of students. The practical case is that any learning topic j in $T(Step_i)$ misunderstood will promote the student with a wrong response to pedagogical step i. It means that the degree of misunderstanding the learning topic j is increased when a student answers wrong for pedagogical step i. Consequently, for each learning topic in $T(Step_i)$, the domination of misunderstanding by pedagogical step i may vary during the student's learning process. Hence, these dominations have to be adapted to meet the individual differences.

$$f(y) = \begin{cases} 1 & \text{if } y > 1; \\ y & \text{if } 0 \leq y \leq 1; \\ -1 & \text{if } y < -1; \end{cases}$$

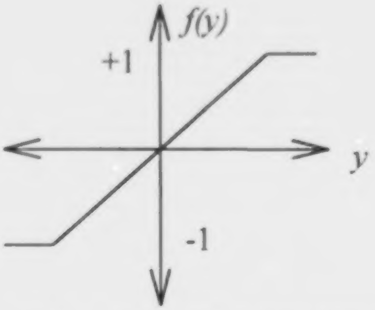

Fig. 4. Processing unit in H-hidden layer using a transfer function.

For each pedagogical step i, if a student's answer is right, he or she may understand all the learning topics j in $T(Step_i)$. Hence, the domination of misunderstanding all learning topics j in $T(Step_i)$ by pedagogical step i is decreased. In other words, the u_{ij} for all j are decreased when $Step_i < 0$ (or the student's answer is right for pedagogical step i). Because the learning topics j in $T(Step_i)$ may be understood by the student, the weights u_{kj} for $j \in T(Step_k)$ have to be decreased. It also means that the weight on any connection to the learning topics j is decreased. Furthermore, for other pedagogical steps k (or $k \neq i$) and learning topics $j \in T(Step_k)$, the weight on any connection between $Step_k$ and other learning topics l ($l \neq j$) is increased since the domination of misunderstanding learning topics j by $Step_k$ is decreased. The heuristics of adaptation on U for $Step_i < 0$ are implemented in the following algorithm:

```
ALGORITHM ADAPTATION($U$, $i$)
1. FOR all $j \in T(Step_i)$ DO
2. $u_{ij} = u_{ij} - \varepsilon$;  $\varepsilon$ is a small constant and $\varepsilon < 1$
3. FOR all $k$ and $j \in T(Step_k)$ and $k \neq i$ DO
```

```
        $u_{kj}=u_{kj}-\varepsilon$;
        FOR all $l \in T(Step_k)$ and $l \neq j$ DO $u_{kl}=u_{kl}+\varepsilon$;
    END FOR
END FOR
END ALGORITHM
```

V. Suggestion Decision

In this section, we will explain the neural subsystem "Suggestion Decision". This neural subsystem is for deciding which topic has to be enhanced.

5-1 Neuron definitions of S_i

Our final goal in this neural network is to judge where a student's misunderstanding are located, and makes a recommendation so that a tutor can address the student's weaknesses. In the preceding sub-network, our neural network has determined the understanding/misunderstanding levels of all concepts. In this output layer, it is interconnected by a lateral-inhibition way. This ensures that only the neuron with the highest activation level will output a one; all others will be zero.

In our neural network, a neuron with an output value of one means that the network suggests a tutor should teach the concept identified by this neuron. Taking an example related to the exponent and logarithm curriculum mentioned in Figure 1, neurons in the output layer represent the suggestion concerning the learning topics: the exponent definition, the exponent property, the logarithm definition, the relation of exponent and logarithm, and the logarithm property, respectively. If the output vector is (0,1,0,0,0), it suggests a tutor should teach the topic of the exponent property.

Consequently, in the output layer, the network will output the value of a suggestion, S. S represents a suggestion to the tutor about whether it needs teaching or not. When $S_i=1$, it is a suggestion to enhance concept i. Otherwise, $S_i=0$ means that there is no suggestion for the relearning of topic i.

5.2 Competitive neural connection

In the previous neural sub-network, the network analyzes the student level via the output neurons of the "History Record" sub-network. The lower a student's level is, the more necessary the improvement is for the corresponding topic. This is to say that we need to find the weakest learning topic and then inform the tutor to rebuild the student's concept. Now we have to control the problem that the network compares all the student's levels for learning topics and points out the worst.

Among current neural network paradigms, there is a type that can do the work mentioned above. It is the competitive learning network (Hertz et al., 1991). Incorporating the competitive learning network into our neural network is the task of the "Suggestion Decision" sub-network.

In competitive learning, only one output unit is on at a time. The output units compete for being the one to fire, and are therefore often called winner-take-all units (Rumelhart & Zipser, 1985). The connections in the competitive neural network are constructed as follows:

(1) A full connection is made between the hidden layer and the output layer. The connections are excitatory.
(2) A full connection is made between output units. The connections are inhibitory.
(3) Each neuron has a self cycle in the output layer. The connections are excitatory.

After receiving H as inputs in the "Suggestion Decision" neural sub-network, only one of the output units, called the winner, can fire at a time. The winning unit is pushed to its maximum value, while all others are forced to their minimum value. The connection matrix V in this sub-network is not introduced here because the competitive learning connection is a standard paradigm in the neural network field. In the competitive network, the winner is the unit i' with the largest net input $\Sigma v_{ji'}C_j$.

VI. Results and Conclusions

The proposed neural-based model was tested using "exponents and logarithms" as an application domain and its hierarchical tree is shown in Figure 1. Suppose that there is a domain expert setting some checkpoints to verify the learner's concepts in a learning environment. There are ten checkpoints in sum: one belongs to an exponent definition, four belong to an exponent property, one belongs to a logarithm definition, one belongs to a relation of exponent and logarithm, and three belong to a logarithm property, respectively. This relation of detailed contents for those checkpoints is listed in Appendix, and the resultant neural network is shown in Figure 5, which also shows the initialization of connection matrix U and V.

The function $T(Step_i)$ is defined in Table 1.

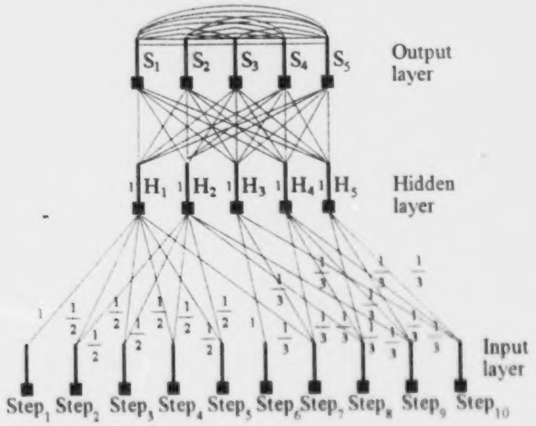

Fig. 5. Expmple network for the "exponents and logarithms" curriculum.

Using the table, we can set the initial values of U and V in the proposed neural model as given in Figure 5.

Suppose that we have a learning sequence which contains 10 pedagogical steps. According to the student's responses, we get a record of (+1, -1, +2, +4, -2, +5, -3, -5, +7, +6). A term "+*i*" indicates that the student's response for ith step is wrong, and "-*i*" indicates the student was correct.

Some experimental results as shown in Table 2. In the table, the first column "Seq. No." means the number of the learning sequence. The second column "Step No." indicates the relevant pedagogical step and the corresponding response. The third column "H" stands for a student's history. Because there are five learning topics in my experiment, we need to produce data for H_1, H_2, H_3, H_4 and H_5. The last column "S" is the suggestion to the tutor. In the table, the results show that the learning history is dependent on the student's responses during pedagogical steps and also suggest which learning topics to enhance. Table 3 shows another set of results for learning sequence of (+8, +9, +7, +10, -1, +6, +10, -2, -6).

Our aim is to develop an approach to student modeling based on a neural network. This network has the subsequent features:

Table 2. Experimental results for ε=0.1

Seq	Step			H					S		
No.	No.	H_1	H_2	H_3	H_4	H_5	S_1	S_2	S_3	S_4	S_5
1	+1	1.000	0.000	0.000	0.000	0.000	1	0	0	0	0
2	-1	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0
3	+2	0.400	0.500	0.000	0.000	0.000	0	0	0	0	0
4	+4	0.800	1.000	0.000	0.000	0.000	0	1	0	0	0
5	-2	0.400	0.500	0.000	0.000	0.000	0	0	0	0	0
6	+5	0.900	1.000	0.000	0.000	0.000	0	1	0	0	0
7	-3	-0.100	-0.200	0.000	0.000	0.000	0	0	0	0	0
8	-5	-0.900	-1.000	0.000	0.000	0.000	0	0	0	0	0
9	+7	-0.867	-1.000	0.333	0.333	0.000	0	0	0	0	0
10	+6	-0.867	-1.000	1.000	0.333	0.000	0	0	1	0	0

Table 3. Experimental results for ε=0.1

Seq	Step			H					S		
No.	No.	H_1	H_2	H_3	H_4	H_5	S_1	S_2	S_3	S_4	S_5
1	+8	0.000	0.333	0.000	0.333	0.333	0	0	0	0	0
2	+9	0.000	0.666	0.000	0.333	0.666	0	0	0	0	0
3	+7	0.333	0.666	0.666	0.999	0.666	0	0	0	1	0
4	+10	0.333	0.999	0.333	1.000	0.999	0	0	0	1	0
5	-1	0.667	0.999	0.333	1.000	0.999	0	0	0	1	0
6	+6	-0.667	0.999	1.000	1.000	0.999	0	0	1	0	0
7	+10	-0.667	1.000	1.000	1.000	1.000	0	0	1	0	0
8	-2	-1.000	0.400	1.000	1.000	1.000	0	0	1	0	0
9	-6	-1.000	0.400	0.000	1.000	1.000	0	0	0	1	0

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1. It transfers the learning material and structure into the neural network easily. This neural-based student model is easily reconstructed as the subject domain is changed.
2. It is able to receive a student's response at any time and generate the analytical results immediately.
3. It records a student's history.
4. It outputs a suggestion to the tutor.

Our main contribution so far has been in specifying and implementing relatively simple steps that can dynamically update the student's misunderstanding status. We have demonstrated some experimental results based on the domain of "exponents and logarithms" that shows the effect of the proposed approach.

Acknowledgment

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Appendix: Contents of Learning Topics and Pedagogical Steps

pedagogical step no.: 1

related learning topics: exponent definition

type: test

content:
please answer the following problem:
====> If a>0, $f(x)=a^x$, $f(x)$ is a Function of an (1) Exponent or a (2) Logarithm?

pedagogical step no.: 2

related learning topics: exponent definition and exponent property

type: material demonstration and dialogue

content:
Exponent-property 1: $a^x \times a^y = a^{(x+y)}$
Please give an example of this property:

pedagogical step no.: 3

related learning topics: exponent definition and exponent property

type: material demonstration and dialogue

content:
Exponent-property 2: $a^x / a^x = a^{(x-y)}$
Please give an example of this property:

pedagogical step no.: 4

related learning topics: exponent definition and exponent property

type: material demonstration and dialogue

content:
Exponent-property 3: $(a^x)^y = a^{(x \times y)}$
Please give an example of this property:

pedagogical step no.: 5

related learning topics: exponent definition and exponent property

type: material demonstration and dialogue

content:
Exponent-property 4: $a^x \times b^x = (a \times b)^x$
Please give an example of this property:

pedagogical step no.: 6

related learning topics: logarithm definition

type: test

content:
Please answer the following problem:
====> If $a>0$ and $a \neq 1$; $f(x)=\log_a(x)$, $f(x)$ is a Function of an (1) Exponent or a (2) Logarithm?

---

pedagogical step no.: 7

related learning topics: exponent definition, logarithm definition and relationship of exponent & logarithm

type: material demonstration and test

content:
The relationship of exponent and logarithm: $a^x = b <=> \log_a b = x$
Please give an answer for $\log_2 8$:

---

pedagogical step no.: 8

related learning topics: exponent definition, logarithm definition and relationship of exponent & logarithm

type: material demonstration and test

content:
logarithm-property 1: If $a>0$ and $a \neq 1$, then $\log_a(a)=1$, $\log_a(1)=0$
Please give an answer for $\log_3 3$:

---

pedagogical step no.: 9

related learning topics: exponent definition, logarithm definition and relationship of exponent & logarithm

type: material demonstration and dialogue

content:
logarithm-property 2: If $a, x, y>0$ and $a \neq 1$, then $\log_a(x \times y) = \log_a(x) + \log_a(y)$
Please give an example of this property:

---

pedagogical step no.: 10

related learning topics: exponent definition, logarithm definition and relationship of exponent & logarithm

type: material demonstration and dialogue

content:
logarithm-property 3: If $a, x, y>0$ and $a \neq 1$, then $\log_a(x/y) = \log_a(x) - \log_a(y)$
Please give an example of this property:

References

Brown, J.S., Burton, R.R., and Zdydel, F. (1973). A model-driven question-answering system for mixed-initiative computer-assisted instruction. IEEE Transactions on Systems, Man, and Cybernetics, 3, 248-257.

Brown, J.S. and Burton, R.R. (1978). Diagnostic models for procedural bugs in basic mathematical skills. Cognitive Science, 1, 155-191.

Brown, J.S., and VanLehn, K. (1982). Toward a generative theory of "bugs". In Carpenter, T.; Moser, J.; and Romberg, T. (Eds.) Addition and subtraction: A cognitive perspective. New Jersey: Lawrence Erlbaum Associates.

Burton, R.R., and Brown, J.S. (1979). An investigation of computer coaching for informal learning activities. Int Jrnl of Man-Machine Studies, 11, 5-24. (Reprinted in Sleeman, S.H.; and Brown, J.S. (Eds.). Intelligent tutoring systems. London: Academic Press.)

Burton, R.R. (1982). Diagnosing bugs in a simple procedural skill. In Sleeman, D.H.; and Brown, J.S. (Eds.) Intelligent tutoring systems. London: Academic Press.

Carbonell, J.R. (1970). AI in CAI: An artificial intelligence approach to computer-assisted instruction. IEEE Transactions on Man-Machine Systems, 11(4), 190-202.

Carr, B. (1977). Wusor-II: A computer-aided instruction program with student modeling capabilities. AI Lab Memo 417 (Logo Memo 45). Cambridge, Massachusetts: Massachusetts Institute of Technology.

Elsom-cook, M. (1989). Guided discovery tutoring. Guided discovery tutoring: A framework for ICAI research. London: Paul Chapman Publishing.

Greer, J.E., McCalla, G.I., and Mark, M.A. (1989). A computational framework for granularity and its application to educational diagnosis. Proceedings of the Eleventh International Joint Conderence on Artificial Intelligence, 1, 477-482.

Hertz, J., Krogh, A., and Palmer, R.G. (1991). Introduction to the theory of neural computation (pp. 217-228). California: Addison-Wesley.

Rumelhart, D., and Zipser, D. (1985). Feature discovery by competitive learning. Cognitive Science, 9, 75-112.

Self, J. (1990). Bypassing the intractable problem of

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student modeling. In Frasson C. & Gauthier G. (Eds.), Intelligent tutoring systems: At the crossroad of artificial intelligence and education. New Jersey: Ablex Publishing Corporation.

Sleeman, D.H., and Smith, M.J. (1981). Modeling students' problem solving. Artificial Intelligence, 16, 171-187.

Stansfield, J.C., Carr, B., and Goldstein, I.P. (1976). Wumpus advisor I: A first implementation of a program that tutors logical and probabilistic reasoning skills. AI Lab Memo 381. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Stevens, A.L., and Collins, A. (1977). The goal structure of a Socratic tutor. Proceedings of the National ACM Conference (pp. 256-263). Seattle, Washington, New York, Association for Computing Machinery.

Stevens, A.L., Roberts, B, and Stead, L. (1983). The use of a sophisticated interface in computer-assisted instruction. Journal of Computer-Based Instruction, 10(1), 16-19.

VanLehn, K. (1987). Learning one subprocedure per lesson. Artificial Intelligence, 31(1), 1-40.

Wenger, E. (1987). Artificial intelligence and tutoring systems: Computational and cognitive approaches to the communication of knowledge (pp. 70-73). California: Morgan Kaufmann Publishers.

White, B.Y., and Frederiksen, J.R. (1985). Quest: qualitative understanding of electrical system troubleshooting. ACM SIGART Newsletter, 93, 34-37.

類神經網路在學生模組實際製作上之應用

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摘　　要

學生模組在智慧型教學系統中扮演著相當重要的角色。有了學生模組，教學系統在教學與學生學習之過程中就可滿足學生之個別需求。本文將利用類神經網路以建立學生模組，首先老師必須將課程結構與相關之教學步驟設計出，此兩資訊將被量化並放入類神經網路之定義項中，然後此類神經網路會取得學生在學習過程中的反應，並調整網路中之量化值。在量化值之調整中會記錄學生之學習歷程以推論出目前學生之學習狀態。依據此推論之學習狀態，類神經網路會提出學生最弱之學習子題以利教學系統能夠加強學生對該子題之學習。整個研究之目標是利用類神經網路建立學生模組以評估學生之學習狀態，並提供適當之意見給教學系統以決定下一個子題的教學。

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Students' Performance in Learning Calculus with Computers[†]

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ABSTRACT

The purpose of this study was to examine the effects of using computers on college students' performance in calculus. A test was designed to probe students' understanding of the most important concepts of calculus. The test was administered to 44 students who had learned calculus with computers and 47 who had not. Analysis of data indicated: (1) the experimental group scored significantly higher on conceptual understanding in graphical mode ($p=0.019$) and algebraic mode ($p=0.081$); (2) there was no difference between the experiment and control groups on symbolic manipulation skills ($p=0.516$); (3) the experimental group scored significantly higher on understanding and proofing formal definitions ($p<0.000$); (4) the experimental group scored significantly higher on the overall performance ($p<0.000$). In addition, students' attitudes toward calculus were evaluated before and after the treatments. In conclusion, the results obtained in the study showed that the computer treatment was superior to the traditional treatment in achieving students' learning and attitude.

Keywords: calculus, pedagogical method, learning with computers.

I. Introduction

Since Douglas (1986) claimed at Tulane University that many students who took calculus did not complete it successfully and many of those who did finish the course had taken a cookbook course in which all they learned were formulae without understanding what they were, many mathematicians and mathematics educators around the world have explored the diverse ways in which college students understand the mathematical concepts of calculus.

These changes have had an impact not only on curricular practice, but also on pedagogical practice of teaching calculus. Although Tucher (1990) reported that it was not necessary for calculus reform involving computers, most of the current innovations in calculus instruction were centered on the use of computers. It seemed that computers could help to break the strangle of abstract symbolic manipulation hold in most traditional calculus courses; allow a more graphical and numerical approach; and make calculus more interesting and appealing to students. It also seemed (Baumgartner & Shemanske, 1990; Smith & Moore, 1990) that calculus classes became occasions not only for instructors to present mathematics, but also for students to "do" mathematics.

Many famous educators offered their research papers about teaching mathematics with comput-

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ers. They all made a high assessment. In 1990, National Science Foundation (N. S. F.) chose the best ten researches which they subsidized, the researches of Clemson University, Dartmouth College, Duke University, Five College (Amherst, Hampshire, Mount Holyoke, Smith College, University of Massachusetts), University of Illinois, Miami University (Ohio), University of Michigan at Dearborn, New Mexico State University, Purdue University and St. Olaf College were included. N.S.F. gave these calculus projects a positive judgment: "They have responded to the call for a 'lean and lively' calculus with energy and imagination — getting grants, setting up laboratories, developing software, assigning student projects, writing their own textbooks, and rethinking from top to bottom what should go into calculus course. They are changing not only what they teach, but also, what is far more difficult, how they teach. — to introduce to the reader a wide variety of calculus projects with the hope that at least one will fit the reader's needs." Conclusively, they thought that computer teaching was able to help student to overcome the obstacles of learning mathematics, and could make mathematics an interesting subject (Höft & James, 1990; Schwingendorf & Dubinsky, 1990). As a result, teaching with computers has been put into practice in western countries, especially in Europe and USA.

In Taiwan, it has been often observed that calculus students do not learn what their teachers expect. Moreover, there is much evidence that listening to a clear presentation of a mathematical content does not guarantee learning. We believe that all calculus students should go beyond the technique-and-formula conception of calculus and should have a conceptual understanding and clear communication of the concepts in order to futher study and the real-world contexts they will face in their future. According to a constructivist hypothesis that is widely shared among mathematics educators, knowledge is actively built up by the learners when they interact with mathematical learning environments. Therefore, it seems that it is worthy for us to teach calculus with computers as a mean of breaking the strange algebraic manipulation and providing more explanations and examples of the concepts in an effort to increasing understanding on most traditional calculus courses. With the existence of computers, Law (1994) claimed that it could enhance students' abilities on procedural understanding, conceptual understanding, problem solving, generalization, and modeling. Students should be treated as active learners rather than passive recipients of knowledge or the mechanics of executing techniques and formulae to certain routine template problems.

During the past three years, the authors have been involved in the project "Learning Calculus with ISETL in Taiwan" (Law & Chiang 1993, 1994; Law, Chiang & Shih 1995) which was supported by National Science Council in Taiwan. The goal of the project was to investigate whether instructional treatments, both using computers and being based on sound epistemological considerations, may have a substantial effect on the development of students' concept of calculus. In order to teach a calculus course that is more conceptual for students who have taken calculus in high school, pedagogy may be more important than any other factor. We must lead students to be more thoughtful about concepts, more adaptable to non-routine questions, and more tenacious in analyzing mathematical situations. So, an instructional material based on constructivist theory and the mathematical programming language, ISETL, was designed by the authors in order to produce handouts that were available as supplementary materials to the regular content of calculus courses. With these, we hoped that it could lessen the difficulty for students learning calculus, and help students realize the basic concepts of definitions and theorems of calculus more directly. It was hoped students would be able to solve mathematical problems efficiently by computer. Furthermore, it was strongly anticipated that the combination of traditional teaching with the computer would promote students' learning interest and deepen their realization of essential concepts.

With the available of computers and supplementary materials to the regular content of calculus courses, our questions are:

1. Does teaching calculus with computers make any significant difference in students' understanding of the concepts?
2. Is it important to have computer experiences before learning calculus with computers?
3. Does teaching calculus with computers make any significant difference in students' attitudes toward calculus?

II. Method

1. Subjects

The subjects involved in this research were chosen from two standard beginning calculus classes for engineering students at Chinese Culture University in Taiwan. All students in the study had some calculus in high school. The classes were randomly assigned to either an experimental group or a control group. Finally, the numbers of students involved in the experimental group and the control group were 44 and 47 respectively. Of all the subjects in the study, only 2.33% and 17.78% in the experimental group and the control group respectively had some experience with the computer.

2. Instruments

Several instruments, including handouts, achievement tests, and attitude questionnaires were created to address the questions cited earlier. These instruments are briefly reviewed below.

2.1 Handouts

Prior to the study, experimental instructional materials were designed by the authors in order to produce handouts that were available as supplementary materials to the regular content of the calculus course. The aim of the handouts was to facilitate the teaching of calculus with computers, and the technology did not appear to be driving the course, but rather was being used as an aid for students to understand concepts and as a tool to experiment as well as to enhance their ability to interpret the analytic information geometrically and numerically. To determine the suitability of the handouts, two pilot studies were conducted before the study. These pilot studies not only helped to clarify the instructional directions but also pointed out the need of revision of some computer activities. They also provided information about the overall appropriateness of the experimental materials for subjects.

2.2 Pretest

Since there was no randomization of subjects to groups (classes) but rather the use of already established groups, we must have a pretest in order to determine whether the groups are initially equal in precalculus knowledge. A set of questions assessing the students' pretreatment level of mathematics achievement was designed and administered to the subjects in both groups. This test included four components consisting of the concepts of basic algebra, real numbers, rectangular coordination and straight line. The maximum score of the pretest was 40.

2.3 Posttest

The posttest was constructed that aimed to evaluate students' understanding of the most important components of the concepts of calculus. Although it was designed to gather information on the effects of learning calculus with computers, it was just a paper-and-pencil task and no question concerning computer techniques or the mathematical programming language, ISETL, was asked. Therefore, the posttest was used for both experimental and control groups. It had four categories that related to: (1) conceptual understanding in the graphical mode; (2) conceptual understanding in the algebraic mode; (3) symbolic manipulation skills; and (4) understanding and proving of the formal definition. Many calculus instructors may disagree with teaching and proving the formal definition in a beginning calculus course. However, in order to demonstrate a comprehensive understanding of a concept, students have to master and prove the formal definition (Law, 1993). Each category scored a maximum of 25 points, and finally a single composite point of maximum 100 was scored for each subject.

2.4 Attitude Questionnaires

Two sets of attitude questionnaires were designed and the distinctions between them were minor. One was administrated before the treatment and the other after. The purpose of the attitude questionnaires was to try to point out any change in attitudes before and after the treatment.

3. Treatments

3.1 Experimental Group

We believed that all calculus students should go beyond the technique-and-formula conception of calculus and should have a conceptual understanding and clear communication of the concepts in order to meet the needs of future study and the real-world contexts they will face in their future careers. Experimental treatment included a technology component, the computer. Skills were developed in the use of the mathematical programming language ISETL. Then the computer was used as a mean of breaking the strange algebraic manipulation and providing more explanations and examples of the concepts in an effort to increasing and facilitating students' understanding the concepts of calculus.

Instructions consisted of two phases. The first, introductory phase lasted for two weeks and was initially focused on acquisition of the basic ISETL commands and procedures. It was explicitly stated that those ISETL commands and procedures were needed to finish the homework later in the course. As students became proficient in the use of the mathematical programming language ISETL, the concepts of calculus were introduced in the second phase that spanned the rest of the course. There were two different kinds of homework: computer activities and traditional exercises in the course. Computer activities required subjects to read and write some simple programs. Although many calculus instructors may say "no" with the considerations of increasing work load and difficulty for students to learn programming in calculus courses, the author's response (Law, 1994) is definitely "yes." In fact, the computer activities progressed from asking students: (1) to read some simple programs provided by the handouts; (2) to investigate what the programs did; and (3) to make some modifications on the program. We did expect students to do serious exploratory work on their own, to witness the dynamic nature of mathematical processes, to do mental manipulations of the programs, and finally to write some other new programs. All the activities were linked to calculus concepts. Besides two regular classroom sessions per week, we also provided a two-hour computer-lab-practice time for the students in the experimental group. Students were encouraged to use the practice time, but it was not required. During the practice time, a teaching assistant might demonstrate some of the handouts activities while helping those who appeared to have difficulty.

3.2 Control group

Students in the control group received traditional instruction without using computers. Both groups in the study used the same text book, except the additional handouts were provided to the experimental group. Also, the instructor of the control group provided two-office-hour for those who had troubles.

4. Procedure

The pretest was administered in the first semester before any instruction. Both groups were tested individually during the same week. The first attitude questionnaire was conducted immediately after the pretest. Different treatments for the groups began in the second week of school time and continued throughout the semester. Approximately a week before the end of the semester, the same paper-and-pencil comprehensive posttest was used as a final examination for both groups. The testing took about two hours. Subjects were voluntarily to answer the second attitude questionnaire followed by the posttest. The approach adopted for the study intended to compare the performance of students in the experimental group with that of students in the control group.

5. The assumptions of the Study

In carrying out the study, two assumptions were made.

a. The assignment of teachers to the two groups did not affect students' performance in the study.
b. The two-hour computer-lab-practice and the two-office-hour of the experimental group and control group respectively, did not affect the comparability of the results of the groups in the posttest.

6. The Hypotheses of the Study

Since the purpose of the study was to investigate the effect of two methods of teaching calculus in college level, several hypotheses were as follows:

a. The performances of the two groups were initially equal in precalculus knowledge.
b. The experimental group would score significantly higher on the conceptual understanding in the graphical mode than the control group.
c. The experimental group would score significantly higher on the conceptual understanding in the algebraic mode than the control group.
d. The experimental group would score similarly in the symbolic manipulation skills as the control group.
e. The experimental group would score significantly higher on the understanding and proofing of the formal definition than the control group.
f. The experimental group would score significantly higher on overall performance than the control group.

III . Results and Discussions

3.1 Achievement tests

The results given in Table 1 indicated that no achievement difference between the experimental and control groups existed before the treatments (p=0.415). The prepost indicated that both groups were initially equal in precalculus knowledge. Therefore, we could certainly evaluate the learning results of students by post-test. On the posttest after instruction, the experimental group (mean=74.72) scored significantly higher than the control group (mean=54.08) in overall performance (p=0.000). This implied that the experimental treatment induced changes in students' behaviors. Moreover, although only 2.33% of students in the experimental group (17.78% in the control group) had some experiences with computer, the experimental group still scored significantly higher than the control group. It also indicated that it was not so important to have computer experience before learning calculus with computers in the study.

To determine the effect of the experimental treatment across each of the stated categories above, we found the questions in the categories of the conceptual understanding in the graphical mode (p=0.019), the conceptual understanding in the algebraic mode (p=0.081), and the understanding of the formal definition (p=0.000) did significantly favor the experimental group (19.63; 18.83; 15.71) over the control group (17.34; 17.44; 9.31). Moreover, the mean scores of the symbolic manipulation skill category showed no differences between the experimental and control groups existed (p=0.516). It revealed that teaching calculus with computers did foster students' understanding of calculus concepts. Also, it seemed that there was no bad effect on students' ability of algebraic manipulation skills. Overall, the use of computers in the course seemed to be effective in developing what we wanted our students to have.

Attitude questionnaires. Since teaching calculus with the computer would increase the work load and difficulty for students, we do expect experimental group may have a negative attitude toward it. But that was not the case. Although there was no significant difference between, the fondness for calculus in the groups before (p=0.264) and after (p=0.193) the treatments, we could see from Table 2, that the percentage of "Agree" was increased in the experimental group and decreased in the control group.

According to a constructivist theory, knowledge is actively built up by the learners when interacting with mathematical learning environment. If students want to understand and develop a concept, they have to construct knowledge from their own action on the environment actively. Therefore, when a student confronts a trouble or is in a stage of disequilibrium, he or she has to be willing to reestablish equilibrium through assimilation and accommodation in order for any cognitive developmental change to occur.

From Table 3, we could see that more than half of the students were actively to solve problems in high school (60% and 65.12% before treatment), but the percentages decreased in college (36.96% and 54.76% after treatment). The reason of the percentages decreased in both groups, I guess, is the absence of the pressure of the College Entrance Examination. Although there was no difference between the groups before the treatment (p=0.620), we had found that there was a significant difference after the treatment (p=0.049). It revealed that the treatment might have some effect to make the rate decrease slowly for the experi-

Table 1. Distribution of the Mean Scores by Groups and Measures.

Variable	Exper.	Cntrl.	p=
Pretest	29.93	29.15	0.415
Posttest	74.72	64.08	0.000
Graphical mode	19.63	17.34	0.019
Algebraic mode	18.83	17.44	0.081
Manipulation skills	20.55	19.99	0.516
Formal definition	15.71	9.31	0.000

Table 2. Distribution of the Percentages in Attitude Question 1.

I like calculus.

		Agree	Neutral	Disgree
Before treatment	Cntrl.	53.49	34.88	11.63
p=0.264	Exper.	46.67	48.89	4.44
After treatment	Cntrl.	45.24	45.24	9.52
p=0.193	Exper.	56.52	41.30	2.17

Table 3. Distribution of the Percentages in Attitude Question 2.

I will try my best to solve any trouble I have in the course.

		Agree	Neutral	Disgree
Before treatment	Cntrl.	60.00	40.00	0.00
p=0.620	Exper.	65.12	34.88	0.00
After treatment	Cntrl.	36.96	63.04	0.00
p=0.049	Exper.	54.76	40.48	4.76

mental group.

As mentioned above, all calculus students should go beyond the technique-and-formula conception of calculus and should have a conceptual understanding of the concepts. For this reason, we investigated whether using computers might change the situation. From Table 4, we could see that most of the students treated calculus as a set of techniques in high school (62.22% and 70.09% before treatment) and there was no difference between the groups (p=0.304). Moreover, the percentages of the control group in each category had almost no change before and after the treatment. But we had found that the percentage has a great shift to "Concepts" in the experimental group after the treatment. Moreover, there was a significant difference between the groups after the treatment (p=0.018). This difference indicated that the treatment did promote students beyond the technique-and-formula conception of calculus .

As we stated above, only 2.33% of students in the experimental group had prior experience with computer. We would like to know whether they had any difficulty in using computers. The result (Difficult, 11.9%; Neutral, 52.38%; Easy, 35.72%) agreed with our previous finding that it was not very important for students to have computer experiences before learning calculus with computers. We also asked students to evaluate the effect of the use of computers in the course. The result (High, 42.86%; Middle, 45.24%; Low, 11.90%) showed that students were very appreciated the approach of teaching calculus with computers.

3.2 School evaluation

Besides the evalutaion done by the authors, we had another source to evaluate our approach. At the end of each semester, all the courses in Chinese Culture University are evaluated by students. It includes four categories: instructor's style and enthusiasm; instructor's teaching approach; teaching materials and content; and teaching effects. The overall rating of the calculus course using computers was 92.96. It is usual for students to rate most of the courses as "above average", but it is unusual for students to rate a calculus course as higher as 90. This evaluation provided another evidence that students appreciated the approach of teaching calculus with computers.

Table 4. Distribution of the Percentages in Attitude Question 3.

I trest calculus as a set of				
		Formulae	Techniques	Concepts
Before treatment	Cntrl.	20.00	62.22	17.78
p=0.304	Exper.	20.93	72.09	6.98
After treatment	Cntrl.	19.75	65.22	15.22
p=0.018	Exper.	16.67	42.86	40.48

IV. Conclusion

The results of this research suggested that teaching calculus with the computer can foster students' learning incomprehensible concepts of calculus. According to observation of their learning processes and their performances after treatment, we thought that teaching calculus with the computer does affect students' learning and behaviors. Now, we present several main points from the perspective of teaching calculus with the computer.

1. Calculus courses need to emphasize clear thinking and not merely symbol manipulation. As Small (1991) claimed in his study, we should enable students to conceptual understanding, not mechanics; developing meaningful problem-solving skills, not just memorization of formulae; approaching mathematics as an alive exploratory subject, not just as a description of past work. Student should also be treated as an active learner rather than passive recipient of knowledge. Using the computer in calculus instruction shows promise.
2. Some of the intentions of using the computer are to exploit the graphical, numerical, and symbolical power of the computer for graphing, tedious calculations and certain routine algebraic manipulations, to provide opportunities for students to experiment, as well as to enhance students' ability to interpret the analytic information geometrically and numerically. Therefore, we can use the computer and ISETL language to help them intuitively understand and manipulate definitions and theorems, and to help them learn calculus more effectively. As a result, with the existence of computer, we can show the abstract concepts in concrete form by presenting the concepts numerically and geometrically.
3. Another intention of using the computer is to exploit its power of programming. As Law (1994) claimed that programming can help students

develop procedural and conceptual understanding, problem solving, generalization, and modeling, we should ask students to write more simple programs to illustrate various concepts, and read programming code in order to uncover the underlying concepts behind the algorithms.

4. In Taiwan, students seldom ask questions in class so it is hard for teachers to know what problems they encounter. Thus, we need to encourage students to learn and discuss the concepts with their teachers and other students. In our approach, we found that students discussed warmly and asked questions frequently, in the classroom as well as in the computer-lab. Apparently, computer teaching can improve the difficulty of one-way teaching.

In conclusion, this research revealed that teaching calculus with computers furnished an approach of improvement traditional teaching. Perhaps some hidden problems of teaching calculus with computers are not discovered yet. Further study is needed to investigate this topic. But unquestionably, using computers can provide a new direction for teaching calculus.

References

Douglas, R. G. (Ed.). (1986). Toward a lean and lively calculus. MAA Notes No. 6. Washington, DC: Mathematical Association of America.

Baumgartner, J. & Shemanske, T. (1990). Teaching Calculus with True Basic. In T. Tucker (Ed.), Priming the Calculus Pump: Innovations and Resources. (pp. 33-50). MAA Notes, 17. Washington DC: Mathematical Association of America.

Höft, M. & James, D. (1990). Computer Labs in calculus. In T. Tucker (Ed.), Priming the Calculus Pump: Innovations and Resources. (pp. 141-158). MAA Notes, 17. Washington DC: Mathematical Association of America.

Law, C. K., & Chiang, C. S. (1993). Learning Calculus with ISETL in Taiwan I. NSC Report No. 82-0111-S-034-001. National Science Council, R.O.C.

Law, C. K. (1993). Learning the e-d defintion of continuity. In Proceedings of the Technology in Mathematics Teaching Conference pp. 313-320. London.: Birmingham.

Law, C. K., & Chiang, C. S. (1994). Learning Calculus with ISETL in Taiwan II. NSC Report No. 83-0111-S-034-001A. National Science Council, R.O.C.

Law, C. K. (1994, in press). The role of programming in teaching calculus. Presented in the 7th Annual International Conference on Technology in Collegiate Mathematics, U.S.A.: Florida.

Law, C. K., Chiang, C. S., & Shih, T.S. (1995). Learning Calculus with ISETL in Taiwan III. NSC Report No. 84-2511-S-034-003. National Science Council, R.O.C.

Smith, D. & Moore, L. (1990). Project CALA. In T. Tucker (Ed.), Priming the Calculus Pump: Innovations and Resources. (pp. 51-74). MAA Notes, 17. Washington DC: Mathematical Association of America.

Schwingendorf, K. & Dubinsky, E. (1990). Calculus, concepts, and computer innovations in learning. In T. Tucker (Ed.), Priming the Calculus Pump: Innovations and Resources. (pp. 176-198). MAA Notes, 17. Washington DC: Mathematical Association of America.

Small, D. (1991). Calculus Reform-Laboratories- CAS's. In L. Leinbach, J. Hundhausen el. (Eds.), The Laboratory Approach to Teaching Calculus. (pp. 9-14). MAA Notes No. 20. Washington DC: Mathematical Association of America.

Tucker, T. (Ed.) (1990). Priming the Calculus Pump: Innovations and Resources. MAA Notes, 17. Washington DC: Mathematical Association of America.

微積分電腦教學對學生表現之探討

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摘　要

本研究嘗試探討微積分電腦教學對學生表現之影響。樣本爲中國文化大學工學院一年級學生，共91人，其中實驗組44人，對照組47人。研究結果顯示：A實驗組對圖形和代數表徵的概念瞭解較對照組之實驗平均分數高；B實驗組和對照組在符號運算技巧上之實驗平均分數沒有顯著差異；C實驗組對概念的定義及證明較對照組之實驗平均分數高；D在整體表現上，實驗組較對照組之實驗平均分數高。總括來說，本研究的結果顯示微積分電腦教學對學生學習成績及學習態度皆有正面之影響。

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Teaching Mathematics Methods Using Videodisc

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ABSTRACT

An multimedia-based instructional system was developed and piloted with preservice elementary teachers. Four mathematics methods classes experienced either lecture supplemented with a new instructional multimedia system or lecture without such material. Subjects who received the system-enhanced instruction appeared more knowledgeable about teaching mathematics using manipulatives than those who received traditional instruction only. Results suggest that multimedia can have beneficial effects for preservice teacher training.

Keywords: Multimedia, Videodisc, Mathematics Methods, Manipulatives, Elementary, Preservice

I. Teaching Mathematics Methods Using Videodisc

Teaching mathematics is a complex process which requires a teacher to utilize many types of information (e.g., subject matter, pedagogy, instructional contexts, manipulatives, social-motivational factors) that are often not adequately addressed by teacher preparation programs (Goldman & Barron, 1990). Much frustration exists for both student-teachers and teacher educators because most prospective mathematics teachers are competent in subject matter and well-versed in instructional theory, yet they appear inept at applying this information when providing explanations for mathematical relations, concepts, or operations. (Commission on Standards for School Mathematics of NCTM, 1989). What is even more perplexing is that teachers who are aware of the discrepancy between their knowledge and their performance in the classroom seem unable to correct their performance (Berliner, 1986; Goldman & Barron, 1990).

Efforts to ameliorate this problem have traditionally centered on introducing additional concepts for prospective teachers to use in the classroom for a student's understanding of mathematics. One such concept is the use of mathematics manipulatives. Mathematics manipulatives are physical objects that teachers use to demonstrate a mathematical operation or concept and allow children to directly manipulate them in order to facilitate their understanding and skill of the operation or concept (Hatfield, Edwards & Bitter, 1993). Researchers (e.g., Akers, 1986) have indicated that using manipulatives to teach mathematics concepts augment elementary student performance and their attitude towards mathematics in general. Sowell (1989) recently reviewed 60 studies that examined mathematics manipulatives. She concluded that, indeed, these devices are useful for learning mathematics knowledge and skills when they are used to make learning an active process (i.e., allow children to actually use the manipulatives) and when children are allowed to manipulate physical objects as often as possible when studying mathematics. Moreover, manipulatives used in mathematics instruction seem to motivate students to work and learn, stimulate mathematical reasoning, and appear to be an informal introduction to higher reasoning in mathematics (Hatfield, Edwards & Bitter, 1993; Sowell, 1989).

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More recently, educational researchers have attempted to incorporate "real life" scenarios in teacher training programs whereby prospective mathematics teachers observe actual classroom instruction. Research suggests that preservice teachers learn more and can transfer that knowledge to their craft of teaching when important instruction on pedagogy is experienced in context (e.g., anchored or situated instruction) (Bransford, Sherwood, Vye, & Rieser, 1986; Palincscar, 1989). Observations in elementary classrooms provide the preservice teacher with a sense of the reality of the instructional environment, but are often limited in allowing learning of teaching theory, mathematics instruction, or learning important aspects of exemplary instruction in general (Carter, Sabers, Cushing, Pinnegar, & Berliner, 1987; Goldman & Barron, 1990). The use of selected videotaped examples from actual classroom teaching lessons provides a non-obtrusive method of demonstrating good and bad mathematics teaching, but without some kind of focus, direction, interaction, or narration to point out specific attributes of good and bad instruction, novice teachers may not notice or may misinterpret fundamental points of quality teaching (Berliner, 1986; Carter, et al., 1987; Goldman & Barron, 1990; Lampert & Ball, 1990). For this reason, a hypermedia-based, instructional program for preservice teachers has been suggested to improve their training and, ultimately, the quality of elementary mathematics education (Copeland, 1989; Goldman & Barron, 1990; Harvard, 1990). Accordingly, the use of interactive technology would allow preservice teachers to develop their perceptual, interpretational, and decision-making skills as well as transfer their training in theory to classroom instruction (Copeland, 1989; Goldman & Barron, 1990).

The promise of videodisc technology as an effective medium for teacher training is a function, in part, of its unique characteristics. A user can control the learning sequence, the subject matter, the form of a lesson's presentation, the speed at which a lesson is presented, and the pace at which a user progresses through the material (King, 1990; Litchfield, 1990). A user has access to a variety of visual and audio presentations and graphic displays. Because of a vast storage capacity (a completed videodisc contains 54,000 individual visual frames), videodisc systems provide multiple pathways for accessing information including realistic practice exercises, examples to perform and study, problems, and a host of instructional exhibits. A computer can be programmed to control the playback. This allows many different lessons to be developed from one videodisc and the order of playback is completely under the control of the user. Although schools have been slow in incorporating its use in their curricula, the benefits that have been reported from those that have are most encouraging. High achievement motivation, less instructional training time, and general increases in teaching performance have been notable outcomes of interactive videodisc instruction (Savenye, 1990). While the majority of educational videodiscs are used as ancillary instructional activities or for individual instructional modules, more and more whole courses in middle and high schools are being taught with routine videodisc sessions (Savenye, 1990).

The purpose of the present investigation was to explore the effectiveness of a multimedia-based videodisc instructional supplement that was developed for a teacher's use in an elementary mathematics education methods course. This undertaking, Teaching Mathematics Methods Using Videodisc (TMMUV), was an NSF funded pilot project, that addressed the need to train preservice teachers in the use of mathematics manipulative and the teaching standards advocated by the National Council of Teachers of Mathematics (NCTM). The objective of the present study was to explore the added instructional value that can be attributed to the TMMUV prototype classroom presentation mode for enhancing a regular lecture.

II. Method

1. Design and Subjects

The present study employed a "nonequivalent control group" design typically used in two-group quasi-experimental designs (Campbell & Stanley, 1966). Four elementary mathematics methods education classes that train pre-service teachers at Arizona State University were used to test the effectiveness of the TMMUV program. Two of the classes were taught by traditional lecture (non-TMMUV group). Two other classes received the identical lecture with the addition of the TMMUV program system (TMMUV group). Randomized assignment of subjects to each class/group was not possible. However, the inclusion of an extra group in each condition compensated, to some degree, for the lack of randomization by the use of "retrospective pretests" to compare differences between the two groups on the dependent measures (Campbell & Stanley, 1966). Examination of posttest scores for two classes in each condition increases confidence in the validity of differences found that are thought to be due to the independent manipulations.

Subjects were 99 undergraduate, elementary education majors enrolled in four preservice methods courses (TMMUV: n=33 & 17; non-TMMUV: n=28 & 21). Classes were assigned to groups so as to result in nearly equal numbers of subjects in each group. Data were to be collected by the TMMUV standalone system used in the laboratory, following the treatment. Bugs in the standalone mode, however, resulted in the loss of 28 subjects from the non-TMMUV group, and five subjects from the TMMUV group. Pencil-and-paper instruments were then substituted for all subsequent data collection. There were no significant age differences between the TMMUV and non-TMMUV groups (means=28.87 and 28.89, respectively). An analysis of the prior knowledge levels of subjects in each class revealed two important differences between the TMMUV and non-TMMUV groups prior to conducting the instruction. Subjects in the non-TMMUV groups had more previous experience using geoboards to teach mathematics as reflected in their reported information (means of 1.24 vs. 2.68 for the TMMUV and non-TMMUV groups, respectively). A significant proportion in the non-TMMUV group also reported having been taught with geoboards as elementary students themselves (means of 1.05 vs. 2.72). The non-TMMUV group scored higher on a measure of academic ability. By combining scholastic aptitude test or achievement test scores with previous grade point averages into inter-quartile categories, it was revealed that subjects in the non-TMMUV groups had higher estimated academic ability, on average, than those in the TMMUV classes (means of 3.17 vs. 2.80). Although this between group difference was not statistically significant, it may be worth noting when examining the effects of TMMUV-enhanced instruction on the attitudes and motivation for using manipulatives.

2. Materials and Instruments

A multifaceted, video database and instructional system (TMMUV) was created that combined full-motion video, digitized audio, text, and graphics to give preservice teachers multiple views of exemplary classroom instruction using teaching methods with manipulative materials that were proposed by the NCTM. Three instructional modes of the system are possible: (a) classroom presentations given in a traditional manner where the instructor displays the program to the students; (b) a standalone tutorial mode which allows students to work through the program at their own pace; and, (c) a video database whereby the student is afforded an opportunity to interactively explore video illustrating the application of specific NCTM teaching standards. For this study, the TMMUV video was projected, in a linear fashion, on a screen.

The TMMUV system is based on the IBM PS/2 microcomputer with M/Motion Video and M/Audio Adapters, and an attached videodisc player. A 32 bit operating system/2, version 2 (OS/2) was used for TMMUV (a 386, 486, or higher family microprocessor is necessary for the system's implementation). The overall structure for the software consisted of (a) multimedia database that included a video and audio library, a three dimensional animation and graphics library, a lesson template library, and a Structured Query Language (SQL) index; (b) interactive graphical interface; (c) authoring shell program; (d) classroom presentation program; (e) laboratory tutorial program; and, (f) an on-line user's guide.

Multiple views of exemplary classroom instruction using teaching methods with manipulative materials proposed by NCTM were used in the present investigation. Types of manipulatives and their content that can be used with TMMUV are shown in Table 1. Two 30-minute videodiscs of elementary mathematics instruction using the manipulatives were developed for use in the prototype. One videodisc contained 189 clips of instruction with geoboards and another disc contained 84

Table 1. Mathematics Manipulatives and Associated Content

Manipulative	Content
Geoboards	Arrays
Greenies	Congruency
Posterboard Shapes	Coordinate Geometry
Shapes	Flips
	Geometric Shapes/Figures
	Properties of Shape
	Reflections
	Right Angles
	Rotation
	Similarity
	Symmetry
	Unit of Measure
	Visualization Skills

clips of instruction with base 10 (numeration) blocks. The geoboard is a manipulative used to build logical thinking and problem solving skills as students investigate shape, symmetry, conguence, angles, areas, perimeters, square roots and functions. Numeration blocks are used to model ones, tens, hundreds and thousands and to build mental, images and understanding of the numeration system. The video clips on each disc ranged in length from 1-second still images to 120-second segments of instruction. In this particular study, selected clips from both videodiscs were used.

3. Measures

There were two measures of the effectiveness of the TMMUV prototype system. It was hoped that such materials would increase a preservice teacher's knowledge of quality instruction. This was termed *cognitive gain*. Six "retrospective pretest-posttest items" were used to assess changes in perceived knowledge and competence to teach with geoboards. Retrospective pretest-posttest items have been suggested as a means of investigating knowledge gain in content areas where subjects have no prior knowledge (Campbell & Stanley, 1966; Rockwell & Stevens, 1992). Five of the items were specific-knowledge referents (e.g., perceived competence to convey ideas of "estimation," knowledge of how to help students feel comfortable in the classroom) and the sixth was more general; i.e., "knowledge of what it is like in the elementary classroom." Items were measured on a 7-point, semantic-differential scale with endpoints labeled 0% and 100%. The subjects were to place a "B" on the scale to indicate where they felt they were before the classroom instruction. They were to write an "N" on the space that they felt they were *now*, after receiving the instruction.

Cognitive gain was further measured using three (3) open-ended questions that required subjects to give their opinions concerning the teacher in the video segments. The questions were: (a) "How did the teacher indicate to the students that it was all right for them to give an answer that was something other than the correct answer?;" (b) "What important teaching strategy did the teacher use to teach the concept of area?;" and, (c) "What did the teacher do that shows a way of making young children comfortable in the classroom?"

Test-retest reliability for the questionnaire was assessed by correlations of the same single-item scale given twice (attitude toward classroom instruction: $r=.78$; $p<.01$). Alpha reliability coefficients were obtained from multi-item scales of attitudes toward mathematics and attitude towards the classroom instruction; .83 and .88, respectively. Face validity was assessed by correlating "knowledge to teach with geoboards after classroom instruction" and "preparedness to teach with geoboards after classroom instructions:" $r=.61$, $p<.01$. A comparison between attitude towards mathematics and attitude toward classroom instruction using geoboards revealed satisfactory

Table 2. Study Design

Group	Intended *n*	Obtained *n*	Treatment
Non-TMMUV Class #1 (*n*=28) Class #2 (*n*=21)	49	21	lecture only
TMMUV Class #3 (*n*=33) Class #4 (*n*=17)	50	45	lecture & TMMUV

convergent validity as evidenced by the correlation of different measures of the same trait: attitude toward instruction ($r=.56, p<.01$) and attitude toward mathematics ($r=.68, p<.01$).

4. Procedure

To determine the additive effect of TMMUV on conventional instruction, four intact elementary mathematics methods classes were assigned to two groups, so as to achieve groups of nearly equal size, as reported in Table 2. One group received the TMMUV-enhanced instruction and one group received only conventional instruction on the same material. There were no significant pre-existing differences among the classes according to available data (e.g., age, sex, academic achievement).

To assure similarity in instruction, an outside instructor taught the same geoboards lesson to all four classes, each of which lasted 110 minutes. The TMMUV system was used to supplement the instruction of the TMMUV group classes. The video included a selection of appropriate videoclips needed for the posttest in both groups. These posttest clips had to be conceptually related to, but distinctly different in all other respects from, the clips shown in the TMMUV group during instruction. Following the instruction, these different clips were shown to subjects in both groups and the instrument was administered.

III. Results and Discussion

The subject's responses to the retrospective pretest-posttest items were averaged across groups and response categories were compared using the independent *t*-test for statistical significance. The scoring criterion for the open-ended questions utilized subject's responses in the form of sentences reflecting their perceptions and beliefs for the contrived situations. A seven-(7) point scale was constructed where by each question was graded according to clarity of expression indicating a "good-bad" range or exact sense of the correct answer (a score of 7) versus no idea what the solution would be (a score of 0). Two independent judges scored the questions. When a conflict arose in scoring, a solution was decided in consultation. There were two general categories of results. An analysis of the pre-instructional differences was conducted in order to determine if there were any variables that could have influenced the post-treatment effects.

Both groups showed gains on pretest-posttest knowledge and performance gain items. The TMMUV-enhanced groups indicated higher overall gain, but only one between-group difference was significant.

Subjects who were exposed to the TMMUV instructional system demonstrated a higher degree of observational power than the subjects in the non-TMMUV groups, as illustrated in Figure 1. When the results of the three open-ended questions were combined, the TMMUV and non-TMMUV groups had means of 5.54 and 4.27, respectively, $t(1.66)=5.36$, $p<.01$. Subjects were asked to indicate their gain in knowledge of the reality of the elementary classroom. Those in the TMMUV group indicated higher cognitive gain than those in the non-TMMUV group [means of 1.95 vs..92, $t(1, 64)=2.05$; $p<.05$].

In the present study, a new technology-based method for teaching preservice, elementary teachers to use mathematics manipulatives in the classroom was piloted. Given the prototypical nature of the TMMUV system and its relatively brief use in the class instructional sequence, it is not surprising that between-group differences for motivation to teach with geoboards and feelings of preparedness to teach with geoboards were not significant. Despite the problems encountered in this study, evidence was found for the utility of the system. Even though there appeared to be significant learning disadvantages for the subjects in the TMMUV group, who had less experience with geoboards (and manipulatives in general), these subjects outscored the non-TMMUV group on the measures of cognitive gain and overall performance.

The subjects in the TMMUV group viewed

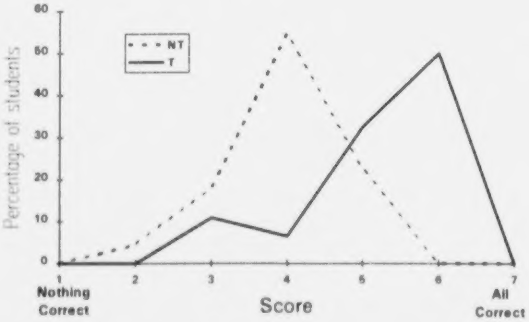

Fig. 1. Comparison of TMMUV and non-TMMUV mean scores on the combined objective performance tests.

geoboards as important devices for effective teaching of geometric area and felt that the system increased their knowledge of using geoboards. There was a general feeling among the TMMUV subjects that, by learning mathematics methods using the TMMUV-enhanced instruction, they could gain keen observational skills that they might not acquire with traditional instruction only. In addition, subjects reported that they acquired a very "real" notion of the elementary classroom from the TMMUV system programs. This is an important finding since a major problem of teacher training is said to be adequately preparing a teacher for the "real classroom" world. Overall, the subjects in the present study indicated that the TMMUV system made important contributions to their learning of mathematics methods, using manipulatives, and teacher training. The results of using the system indicate a future for interactive multimedia in teacher training that is worthy of closer scrutiny and effort in devising better systems for teachers and students.

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References

Akers, J. (1986). *California curriculum commission report of mathematics materials*. California: California Curriculum Commission.

Berliner, D. C. (1986). In pursuit of the expert pedagogue. *Educational Researcher*, *15*, 5-13.

Bransford, J. D., Sherwood, R., Vye, N. J., & Rieser, J. (1986). Teaching thinking and problem solving: Research foundations. *American Psychologist*, *41*, 1078-1089.

Campbell, D. T., & Stanley, J. C. (1966). *Experimental and quasi-experimental designs for research*. Boston, MA: Houghton Mifflin.

Carter, K., Sabers, D., Cushing, K., Pinnegar, S., & Berliner, D. C. (1987). Processing and using information about students: A study of expert, novice, and postulant teachers. *Teaching and Teacher Education*, *3*, 147-157.

Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics. (1990). *Curriculum and evaluation standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.

Copeland, W. (1989). Technology-mediated laboratory experiences and the development of clinical reasoning in novice teachers. *Journal of Teacher Education*, *40*, 10-18.

Goldman, E. S., & Barron, L. C. (1990). Using hypermedia to improve the preparation of elementary teachers. *Journal of Teacher Education*, *41*, 21-31.

Harvard, G. (1990). Some exploratory uses of interactive video in teacher education: Designing and presenting interactive video sequences to primary student teachers. *Journal of Aett, Educational & Training Technology International*, *24*, 155-173.

Hatfield, M. M., Edwards, N. T. & Bitter, G. G. (1993). *Mathematics methods for the elementary and middle school*. Boston: Allyn & Bacon, Inc.

King, J. M. (1990). Optical disc technology: Education trend of the future? *Technology-Teacher*, *49*, 25-29.

Lampert, M., & Ball, D. L. (1990). *Using hypermedia technology to support a new pedagogy of teacher education* (Issue Paper 90-5). East Lansing, MI: Michigan State University, National Center for Research on Teacher Education.

Litchfield, B. C. (1990). Criteria for evaluating videodisc interactivity. *Performance and Instruction*, *29*, 23-26.

Palincsar, A. S. (1989). Less charted waters. *Educational Researcher*, *18*, 5-7.

Rockwell, S. K., & Stevens, G. (1992). *How accurate are pretest self-report measures of adults' knowledge and behavior*? Paper presented at the American Evaluation Association, Seattle, WA.

Savenye, W. C. (1990). Instructional interactive video - what works: A review of the research and development literature. *Young Professors Program Monograph Series*, Washington, DC: National Society for Performance and Instruction.

Sowell, E. J. (1989). Effects of manipulative materials in mathematics instruction. *Journal of Research in Mathematics Instruction*, *20*, 498-505.

Teaching Mathematics Methods Using Videodisc

使用影碟數學教學法

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摘　要

一個以多媒體爲基礎的交談式教學系統已發展出來並在一些職前訓練的小學教師身上測試過。四個上數學教學法班級的學生當中，兩班除了接受演講式的教法之外，還接受新的交談式多媒體教學系統輔助。另外兩班則只接受傳統的演講式教法而已。那些有接受輔助教學系統的學生覺得他們自己準備更充分且更有動機去使用操作物。此外，這些接受多媒體教學系統的學生對於使用操作物表現出來得比那些僅接受傳統的演講式教法的學生懂得更多。這個研究的結果認爲交談式多媒體教學系統對於職前教師的師資培育有所助益。

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Beginning Teachers' and Their Students' Conceptions of Science Teaching

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ABSTRACT

This study investigated the changes of beginning chemistry teachers' conceptions of science teaching in their first year of teaching, and how these conceptions differ from their students'. The comparison of pre- and post-test surveys found that the beginning teachers' conception of what constitutes a good teacher is very different from the students' conception. Meanwhile, it seems that the teachers were adjusting their conceptions to fit practical work conditions, while the students stood firmly by their conceptions. In addition, the beginning teachers believed less in the value of laboratory-based science activities than the students did. It is revealed that more efforts are needed to build beginning teachers' confidence and willingness to conduct hands-on science experiments.

Key words: Conceptions of science teaching, secondary education, beginning teachers.

I. Introduction

Increasing attention is being paid to the area of teachers' conceptions about the nature of science (Brickhouse, 1990; Lederman & Zeidler, 1987; Lederman, 1992), and about both science teaching and learning (Hewson & Hewson, 1987; Lawrenz & Lin, 1992; Thompson, 1984). It has been concluded by most of the studies that there is a relationship between teachers' conceptions and their classroom practices, although how these conceptions influence classroom instruction is still not clear. As Brickhouse (1990) described in her case study, teachers who had different conceptions about the nature of science taught science classes differently. When a teacher's view of science is consistent with the contemporary view, s/he is likely to encourage students to be active problem solvers. On the other hand, if a teacher views scientific theories as truths (i.e., logical empiricism), s/he may be more likely to teach science in a way that requires students to follow directions and get "right" answers. Meanwhile, Hewson and Hewson (1987) have shown that both preservice and inservice teachers are likely to hold alternative conceptions of teaching, some of which conflict with the contemporary approach (e.g., constructivist approach) to teaching science, which may interfere with the teachers' tendency of constructing their intended view of teaching. More recently, Aguirre, Haggerty, and Linder (1990) found that 50% of the preservice teachers in their study held the conception that "teaching is a matter of knowledge transfer from the teacher's head and textbooks to the empty minds of children". The two researchers concluded that students entering a teacher education program possess a variety of conceptions about teaching.

By understanding teachers' alternative conceptions, science educators can help teachers recognize the fact that a teacher is actually like a learner. Various misconceptions and prior knowledge are held in a learner's mind which impede the learning of scientific concepts. In order to promote the acquisition of scientific concepts, it is necessary to find out the types of learners' misconceptions. Similarly, in a science teaching methods class or inservice training course, the understanding of teachers' alternative conceptions about science teaching can help science educators facilitate teachers' willingness and efforts to adopt more appropriate conceptions. In particular, when we investigate teachers' conceptions of teaching over one year, we are able to identify changes of their conceptions. Moreover, if the changes are not as expected, it can point out the efforts and directions that should be taken.

Despite the considerable work that has been done to understand the relationship between teachers' conceptions and their classroom practices, little attention has been paid to beginning science teachers' conceptions of teaching. Usually, the first few years of teaching are particularly difficult (Marso and Pigge, 1987). Aware of the existence of difficulties for beginning teachers, Brickhouse and Bodner (1992) checked how a typical beginning teacher adapted when confronted with difficulties. The two researchers concluded that the beginning teacher was struggling to reconcile conflicting conceptions between what is desirable and what is possible within the constraints of preparation and the work situation. During this process of reconciliation, students' reactions could be an important constraint on these teachers' conceptions and behaviors of teaching (Cooney, 1985). Rust (1994) also concluded that new teachers were strongly affected by the conditions of the workplace. The results of these studies revealed that teachers' conceptions are likely to be influenced by students or working conditions, especially for beginning teachers. It is, therefore, of particular interest to check what changes in beginning science teachers' conceptions of teaching have occurred during one year, and how these conceptions differ from their students' view of science teaching. Additionally, by checking both teachers' and students' change of conceptions over time, we can presume either that students' conceptions were influenced by teachers' instruction or that teachers adjusted their conceptions of teaching after interacting with their students.

Instead of using a case study to check a single beginning science teacher's development of teaching conceptions and practices, this study attempted to provide a general picture about what beginning science teachers believe in their minds and how these conceptions changed in their first year of teaching compared to their students' conceptions. Specifically, the purpose of the study was to (1) assess beginning chemistry teachers' conceptions of science teaching in their first year of teaching, (2) assess the conceptions concerning science teaching of junior high school students who were taught by these beginning chemistry teachers, and (3) identify the differences and interactions in the conceptions of science teaching between the beginning chemistry teachers and the junior high school students.

II. Methodology

Eighteen beginning chemistry teachers teaching in fifteen different junior high schools and their 8th grade students (N=760) participated in this study. The beginning chemistry teachers graduated from one of the three universities which provide the preservice training for chemistry teachers in Taiwan. They are about one-fourth of the beginning chemistry teachers in Taiwan. All the teachers were in their first year of teaching and used the same physical science textbook. At the beginning of the school year, all of the eighteen teachers and their 8th grade students were asked to respond to a questionnaire (pre-test) which was derived from the Self Evaluation Questionnaire (Educational Student Affair Office, University of Minnesota 1986) and a questionnaire used for a state-wide chemistry teachers' survey (Lin & Lawrenz, 1992). Upon completion of the questionnaire's Chinese draft version, two science educators were asked to review it. Their comments were taken into consideration. In addition, three 8th grade students and three secondary school chemistry teachers were interviewed and asked to respond the second draft of the questionnaire. An attempt was made to make sure that the intended questions were understood by the respondents. Inappropriate words were modified. Consequently, the Cronbach alpha reliability of the teacher questionnaire was 0.82 pre-test and 0.71 post-test. The reliability of the student questionnaire was 0.88 pre-test and 0.87 post-test. Topics covered in this questionnaire were (1) the objectives of science teaching (Eleven objectives were described, e.g. learning scientific concepts and theories. Following each objective, there was a 5-point Likert scale with 1 as the least important level and 5 as the most important level), (2) the characteristics of a good teacher (Fourteen characteristics were listed, e.g. clarity of explanations. The rating scale for each characteristic was the same as the above one), and (3) the conceptions about science teaching (Five statements were described, e.g. hands-on experimentation is a waste of time. Following each statement, there was a 5-point scale representing the level of agreement, in which 1=strongly agree, 2=agree, 3=undecided, 4=disagree, 5=strongly disagree). In addition to the above questions, the teachers' questionnaire included (4) twelve more questions about teaching methods (e.g. classroom lecture). After each method, the teachers were asked to respond how often they used it. (0=never, 1=once a semester, 2=once a month, 3=once a week, 4=twice a week, 5=almost everytime) At the end of school year, all the 18 beginning teachers and the 760 8th graders responded to the same questionnaire again (post-test). In order to find out rankings in each of the five topics, means and standard deviations were calculated for each question. For the purpose of identifying the ranking differences of each question between the teachers' and the students' responses, independent t-tests were conducted to test the statistical significance. Additionally, dependent t-tests were used to check the pre- and post-test differences in both students' and teachers' ratings.

III. Results

1. Science Teaching Objectives Perceived by Beginning Teachers and Students

The beginning teachers and the students were asked to rank the level of importance of eleven science teaching objectives. Table 1 shows the results ranked by the beginning teachers in pre- and post- tests. This shows that four of the objectives listed in the top five (i.e., developing awareness of safety issues in laboratory, becoming motivated to study science, developing curiosity about natural phenomena, becoming aware of the importance of science in technology and daily life) on the post-test were the same as those in the pre-test, though the rankings were slightly different. The objective of "preparing for further study in science" appeared as the fourth most important objective in the post-test, but it was not ranked as one of the top five most important objectives in pre-test. The mean score of this objective increased the most (from 4.16 to 4.50) among the eleven objectives. The teachers changed only slightly from pre- to post-test in ranking the importance level of the other ten objectives.

Table 2 presents the eleven objectives ranked by the students. The comparison between Table 1 and Table 2 reveals that the students were more consistent than the teachers in rankings. Ten out of the eleven objectives remain in the same ranking sequence on the students' pre- and post-test. In addition, all of the top five objectives were similar to the post-test five objectives selected by the beginning teachers. The objective of "preparing for further study in science" , which appeared fourth among the teachers' top five post-test objectives, matched the ranking given by the students.

Table 1. The Science Teaching Objectives Perceived by Beginning Teachers

	Pre-test		Post-test	
	[a]mean	sd	mean	sd
1. Become motivated to study science.	4.78 (1)*	0.43	4.61 (2)	0.50
2. Develop awareness of safety issues in lab.	4.67 (2)	0.59	4.67 (1)	0.59
3. Learn the application of science in technology and daily life.	4.50 (3)	0.62	4.44 (5)	0.62
4. Develop curiosity and understanding about natural phenomena.	4.50 (4)	0.62	4.50 (3)	0.51
5. Learn how to formulate hypothesis.	4.44 (5)	0.51	4.39	0.61
6. Learn scientific concepts and theories.	4.39	0.50	4.22	0.55
7. Prepare for further study in science.	4.16	0.62	4.50 (4)	0.71
8. Understand the nature of science.	3.89	0.68	3.83	0.71
9. Learn how to design and perform experiments.	3.78	0.94	3.83	1.04
10. Understand the history of science.	3.72	0.67	3.67	0.91
11. Develop practical skills.	3.67	0.97	3.82	0.73

a: The mean score of the improtance level. The higher the score, the more important. sd=standard deviation.
*: Numbers in parentheses are ranks of importance.

Table 2. The Science Teaching Objectives Perceived by Students

	Pre-test		Post-test	
	[a]mean	sd	mean	sd
1. Develop awareness of safety issues in lab.	4.31 (1)*	0.83	4.36 (1)	0.85
2. Develop curiosity and understanding about natural phenomena.	4.13 (2)	0.86	4.21 (2)	0.84
3. Become motivated to study science.	4.00 (3)	0.86	4.15 (3)	0.85
4. Prepare for further study in science.	4.00 (4)	0.86	4.01 (4)	0.86
5. Learn the application of science in	3.98 (5)	0.84	3.96 (5)	0.85
technology and daily life.	3.98 (5)	0.84	3.96 (5)	0.85
6. Learn how to formulate hypothesis.	3.97	0.90	3.96	0.93
7. Learn scientific conceptes and theories.	3.91	0.85	3.95	0.85
8. Learn how to design and perform experiments.	3.88	0.89	3.86	0.95
9. Understand the nature of science.	3.83	0.92	3.84	0.94
10. Develop practical skills.	3.79	0.96	3.89	0.95
11. Understand the history of science.	3.70	1.01	3.68	1.05

a: The mean score of the importance leve. The higher the score, the more important. sd=standard deviation.
*: Numbers in parentheses are ranks of importance.

2. Aspects of a Good Teacher Perceived by Beginning Teachers and Students

Respondents were asked to rank the level of importance of fourteen characteristics of a good teacher. As can be seen from Table 3, four of the top five most important characteristics selected by the beginning teachers in the pre-test were related to teachers' personal capabilities, in other words, were teacher-centered (i.e., clarity of explanations, relating teaching material to students' lives, ability in organizing instruction, and subject matter knowledge), and only one characteristic focused on students, or was student-centered (i.e., encouraging students). However, in the post-test results, two characteristics were student-centered (i.e., encouraging students and respecting students). In contrast to the beginning teachers' responses, the 8th graders ranked student-centered characteristics higher. As shown in Table 4, in both pre- and post-tests, four out of the top five most important characteristics selected by the students were focused on

Table 3. The Characteristics of a Good Teacher Perceived by Beginning Teachers

	Pre-test		Post-test	
	[a]mean	sd	mean	sd
1. Clarity in explanation.	4.94 (1)*	0.24	4.94 (1)	0.24
2. Relating teaching materials to students' lives.	4.78 (2)	0.43	4.61 (3)	0.50
3. Encouraging students.	4.61 (3)	0.78	4.72 (2)	0.46
4. Ability in organizing.	4.56 (4)	0.62	4.61 (4)	0.50
5. Subject matter knowledge.	4.50 (5)	0.51	4.44	0.62
6. Fairness.	4.39	0.78	4.44	0.62
7. Respecting students.	4.33	0.59	4.61 (5)	0.61
8. Interest in students.	4.33	0.59	4.33	0.59
9. Ability of making decision.	4.33	0.39	4.39	0.61
10. Enthusiasm.	4.33	0.69	4.17	0.86
11. Creativity.	4.28	0.67	4.22	0.88
12. Sense of humor.	4.22	0.55	4.56	0.51
13. Capability of taking care of students with various ability levels.	4.06	0.72	4.28	0.83
14. Kindness.	3.22	1.31	3.72	1.23

a: The mean score of the importance level. The higher the score, the more important. sd=standard deviation.
*: Numbers in parentheses are ranks of importance.

Table 4. The Characteristics of a Good Teacher Perceived by Students

	Pre-test		Post-test	
	[a]mean	sd	mean	sd
1. Respecting students.	4.58 (1)*	0.65	4.60 (1)	0.63
2. Fairness.	4.54 (2)	0.76	4.55 (2)	0.75
3. Capability of taking care of students with various ability levels.	4.50 (3)	0.77	4.54 (3)	0.77
4. Interest in students.	4.46 (4)	0.76	4.50 (5)	0.76
5. Clarity in explanation.	4.40 (5)	0.70	4.50 (4)	0.70
6. Enthusiasm.	4.37	0.79	4.37	0.82
7. Encouraging students.	4.36	0.80	4.39	0.79
8. Ability of making decision.	4.34	0.77	4.35	0.75
9. Kindness.	4.26	0.88	4.24	0.93
10. Relating teaching materials to students' lives.	4.22	0.81	4.28	0.81
11. Subject matter knowledge.	4.21	0.81	4.17	0.81
12. Sense of humor.	4.13	0.83	4.15	0.90
13. Ability in organizing	4.12	0.89	4.20	0.76
14. Creativity	3.22	1.31	4.13	0.92

a: The mean score of the importance level. The higher the score, the more important. sd=standard deviation.
*: Numbers in parentheses are ranks of importance.

student-centered aspects (i.e., respecting students, fairness, capability of taking care of students with various ability levels, and interest in students).

Additionally, it is interesting to notice that the least important characteristic of a good teacher ranked by the teachers was "kindness", while the students picked "creativity" instead. It appears that the teachers disregarded this student-centered characteristic at the beginning of their teaching (mean=3.22) and valued it more at the end of the school year (mean=3.72). On the other hand, the students thought teacher-centered characteristics were not important. This can be seen from Table 4, where the last four characteristics were all teacher-centered characteristics (i.e., subject matter knowledge, sense of humor, ability in organizing, and creativity).

3. Conceptions of Science Teaching Perceived by Beginning Teachers and Students

All the beginning teachers and the students

Table 5. Means and Sd's of Opinions about Teaching

	Beginning teachers		Students	
	Pre-test	Post-test	Pre-test	Post-test
1. Science is a difficult subject for children to learn	[a]1.94 (0.94)	2.00 (1.08)	2.51 (1.13)	2.39 (1.11)
2. Hands-on science experiences aren't worth the time.	4.18 (1.01)	3.56 (1.04)	4.13 (1.00)	4.21 (0.96)
3. *Laboratory-based science classes are more effective than non-laboratory-based classes.	2.94 (1.16)	3.00 (1.14)	2.33 (1.13)	2.24 (1.07)
4. ***Only the more able students can participate in problem solving activities.	2.22 (1.16)	2.50 (1.20)	3.88 (1.09)	3.92 (1.19)
5. **The content coverage and difficulty level of the textbook is suitable for students.	4.17	4.44	2.97	3.11

*: The independent t-test both in the pretest mean difference and posttest mean difference between the beginning teachers and the students is significant at the level of P<0.05.
**: P<0.01
***: P<0.001
a: The mean score of the agreement level. The higher the score, the greater the disagreement level. Numbers in () are standard deviations.

Table 6. The Teaching Methods Used by Beginning Teachers

	Pre-test		Post-test	
	[a]mean	sd	mean	sd
1. Classroom lecturing.	4.67 (1)*	0.97	4.83 (1)	0.51
2. Students present answers.	2.89 (2)	1.41	2.78 (3)	1.59
3. Students answer questions from textbooks.	2.72 (3)	0.75	3.17 (2)	1.65
4. Students do hands-on experiments.	2.72 (4)	1.02	1.83 (4)	0.99
5. Students hand in laboratory reports.	1.78 (5)	1.26	1.56	1.20
6. Teacher performs demonstrantions.	1.72	1.27	1.78 (5)	1.22
7. Students discuss in groups.	1.11	1.64	1.67	1.61
8. cooperative groups.	0.70	1.16	1.06	1.26
9. Films, Videotapes.	0.65	0.78	0.67	1.03
10. Students report on projects.	0.53	0.72	0.44	0.62
11. Field trips.	0.11	0.32	0.11	0.32
12. Computer assisted instructions.	0.06	0.24	0	0

a: The higher the mean value, the more frequently the teaching method was used. sd=standard deviation.
*: Numbers in parentheses are ranks of the most often used teaching methods.

were asked to indicate the extent to which they agreed with the statements presented in Table 5. The beginning teachers held significantly different conceptions from the students in three out of the five statements. For example, the students believed that "laboratory-based science classes are more effective than non-laboratory classes" (mean of the agreement level=2.24) more than the beginning teachers (mean of the agreement level=3.00). Secondly, the students disagreed that "only the more able students can participate in problem solving activities" (mean=3.92), while the teachers slightly agreed with the statement (mean=2.50). The third difference of conception between the beginning teachers and the students was over the statement "the content coverage and difficulty level of the textbook is suitable for students". The beginning teachers held a much stronger "disagree" position toward the statement (mean=4.44) than the students did (mean=3.11).

4. The Teaching Methods Used by Beginning Teachers

The question regarding the teaching methods was asked only of the beginning teachers. Table 6 presents the rankings of the commonly used teaching methods reported by the beginning teachers at the beginning and the end of the school year. The comparison between the pre- and post-test results revealed that the rating of " students do hands-on experimenfs" dropped from 2.72 (almost once a week) to 1.83 (almost once a month). Additionally, in the post-test results, the use of "teacher demonstration" becomes one of the top five most often used teaching methods. It appears that in the second semester, instead of letting students do hands-on experiments, the beginning teachers were more likely to use teacher demonstrations. This finding is consistent with the results in Table 5, which shows that beginning teachers felt hands-on experiments were of more value (i.e., #3 in this Table) at the beginning of the school year (agreement mean=4.18) than they did at the end of the school year(agreement mean=3.56).

IV. Discussion

The sample size of the beginning chemistry teachers was small (N=18), though it was representative (Since it constituted about one fourth of each year's population and was evenly distributed through Taiwan). Nevertheless, this study can be looked as a pilot study of a large-scale survey. The findings can serve as the basis of a further, more in-depth inquiry.

It is interesting that the students' conception of what constitutes a good teacher is so different from the conception of the beginning teachers. The students emphasized student-centered characteristics (e.g., interested in students, respecting students, fairness, capability of taking care of students with various ability levels), and disregarded the teacher-centered characteristics (e.g., subject matter knowledge, sense of humor, ability in organizing, and creativity), while the beginning teachers focused on the teacher-centered characteristics (e.g., clarity of explanation, ability of organizing instruction, subject matter knowledge) and disregarded student-centered characteristics (e.g., capability of taking care of students with various ability levels, and kindness). It is not surprising that the students would rate the student-centered characteristics higher, but it is surprising that the teachers weren't more student-centered in their rankings. This result can be partly explained by the findings of Aguirre, Haggerty, and Linder (1990). The three researchers found that half of the preservice teachers in their study view the "teacher as the source of knowledge and teaching is a matter of knowledge transfer". It is suspected that teachers with this conception are likely to be more "teacher-centered" in their teaching. It would be interesting to conduct a further study investigating if this conjecture is true.

Two findings together revealed that the beginning teachers adjusted their methods and conceptions of teaching. First, the frequency rating of "students doing hands-on experiments" dropped from once a week in the pre-test period to once a month in the post-test period. Secondly, the teachers' ranking of "the top five most important characteristics of a good teacher" shifted from "teacher-centered" toward more "student-centered". In contrast, the students kept emphasizing the importance of "student-centered" aspects throughout the year. Therefore, it is suspected that these teachers were adjusting their conceptions and teaching to fit the working conditions, instead of that the students' conceptions were influenced by the teachers. These two findings are consistent with the finding of Brickhouse and Bodner (1992). The beginning science teacher in their study expressed the importance of hands-on experience at the beginning of the school year. However, the need to cover all the content in textbooks and difficulties in preparing supplies needed to do experiments, prevented the beginning teacher from implementing the desired instruction toward the end of the school year. Consequently, the beginning teacher asked students to memorize the terms in the chapters and follow procedures in the textbook exactly to solve problems, instead of encouraging curiosity and creativity in the environment and letting students do their own experiments. During the administration of the questionnaires, many of the beginning teachers expressed their frustrations with classroom management to the researcher, especially in terms of managing the laboratory. It may be that this frustration and the various constraints resulted in a decrease in the frequency of letting their students do hands-on experiments. Further research studies can investigate the extent to which all teachers' (not just beginning teachers') conceptions about the importance of "hands-on science experiences" are related to the frequency of using this teaching method.

Many studies have focused on teachers' conceptions of science teaching (e.g., Aguirre, Haggerty & Linder, 1990; Hewson & Hewson, 1987; Lin & Lawrenz, 1992). This study extended the investigation to students' conceptions of science teaching. It was found that the students' conceptions of science teaching were not influenced by the beginning science teachers at all. From their perceptions about the characteristics of a good teacher, it appears that they expect respect, fairness, careness, and encouragement from their teachers (i.e., student-centered characteristics). They do not care about teachers' creativity, ability in organizing, sense of humor, and subject matter knowledge as much as student-centered characteristics. More importantly, they persist in holding this conception throughout the school year. From the comparison between the teachers' and the students' opinions about science teaching, it was seen that the students were more confident about their ability of doing problem solving than the teachers' perception of the students' ability. Meanwhile, the students did not perceive the currently used texebook to be as difficult as the teachers perceived.

At the end of the school year, both the beginning teachers and the students ranked "preparing for further study in science" as one of the five most important science teaching objectives. However, this objective was not perceived as one of the five most important objectives in the beginning teachers' pre-test. Simply based on the data, we are not able to identify the factors that caused this change. But it would be reasonable to predict that the forthcoming high school entrance examination for the students could be one of the major factors. With this as a priority, beginning teachers might try to cover all the required content using teaching strategies which emphasize memorization of science concepts and knowledge rather than focusing on developing students' scientific processing skills. The same finding was stated by Yager (1986), and he concluded that teachers (no matter whether in elementary or secondary schools) tend to feel that preparing students for further study is their responsibility.

V. Implications for Science Education

This study found that the beginning chemistry teachers emphasized more the "teacher-centered" characteristics of a good science teacher than the "student-centered" characteristics. Though both types of characteristics are important, current constructivists suggest that a learner constructs meaning from new information as a result of an interaction between that individual's prior knowledge and her/his current observation. Therefore, the teachers preparation program should have made prospective teachers aware that a successful teacher should play the role of a facilitator of learning instead of the role of knowledge giver. It is more important to help students learn than to simply give them subject matter knowledge. In addition, the finding in this study about the difference between teachers' and students' expectations toward a good teacher may serve to remind teachers and teacher educators that we should pay more attention to students' needs and expectations in teaching.

The significant difference between the beginning teachers' and the students' conception of the effectiveness of laboratory-based science activities deserves special attention from science educators. Research studies have revealed the importance and value of students' hands-on experiences and laboratory-based activities (Glasson, 1989; Mattheis & Nakayama,1988; Mensch & Rubba, 1989). Unfortunately, this study found that the beginning teachers were not as impressed with the effectiveness of this teaching method as the students were. This conception may prevent the teachers from using this teaching method as frequently as science educators recommend. In view of this result, science educators should try to convince beginning teachers of the benefits of hands-on experience and teach them in detail how to handle laboratory management effectively. School administrators and experienced colleagues should provide emotional support and appropriate assistance in preparing the laboratory supplies and equipment. Additionally, the universities which are responsible for the teacher training should maintain ongoing contact to help the beginning teachers resolve difficulties and frustrations. Hopefully this support could build beginning teachers' confidence and willingness to use hands-on science experiments.

The results of the study reveal that not only teachers but also students believe that preparing for further study in science is one of the most important objectives in science teaching. However, Mitchell (1989) found that the instructors at higher levels do not feel the same way. "Higher level instructors prefer that lower level instructors concentrate on teaching students how to study and think in general, leaving the development of a specific knowledge base about the subject to the experts" (p 564). Yager(1986) also indicated that " there is no evidence that teachers at the higher levels ever recognize the preparation that their students received at the lower levels....... Most high school teachers are negative about junior high science."(p145). In addition to the above two research studies' conclusions, contemporary philosophy of science also asserts that scientific knowledge is changeable, and not accumulated helter-skelter(AAAS, 1989). Teachers should not focus too much on specific content knowledge, since students retain very little of what we teach them. Simply putting emphasis on the mastery of scientific content knowledge does not help or motivate students. We need science teachers to see their primary role as preparing future scientifically literate citizens. Hence, a holistic view of science teaching is recommended.

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References

Aguirre, J. M., Haggerty, S. M. and Linder, C. J. (1990). Student-teachers' conceptions of science, teaching and learning: a case study in preservice science education. *International Journal of Science Education*, **12**, 381-390.

American Association for the Advancement of Science (1989). *Science for All Americans*. Washington DC: Author.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*, **41**(3), 53-62.

Brickhouse, N. W., & Bodner, G. M. (1992). The beginning science teacher: Classroom narratives of convictions and constraints. *Journal of Research in Science Teaching*, **29**(5), 471-485.

Cooney, T. J. (1985). A beginning teachers' view of problem solving. *Journal for Research in Mathematics Education*, **16**(5), 324-336.

Educational Student Affair Office (1986). Self Evaluation Questionnaire. Minneapolis, MN: University of Minnesota.

Glasson, G. E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching*, **26**(2), 121-131.

Hewson, P. W., & Hewson, M. G. (1987). Science teachers' conceptions of teaching: Implications for teacher education. *International Journal of Science Education*, **9**(4), 425-440.

Lawrenz, F. & Lin, H. S. (1992). Teachers' conceptions of teaching and intellectual development. Paper presented at the annual meeting of the American Educational Research Association. San Francisco, CA. April 20-24.

Lederman, N. G. and Zeidler, D. L. (1987). Science teachers' conceptions of the nature of science: do they really influence teaching behavior? *Science Education*, **71**, 721-734.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: a review of the research. *Journal of Research in Science Teaching*, **29**, 331-360.

Lin, H. S. & Lawrenz, F. (1992). A survey of high school chemistry teachers' beliefs and practices. *Journal of Chemical Education*, **69**(11), 904-907.

Marso, R. N. & Pigge, F. L. (1987). Differences between self-perceived job expectations and job realities of beginning teachers. *Journal of Teacher Education*, **38**(4), 53-56.

Mattheis, F. E. & Nakayama, G. (1988). Effects of a laboratory-centered inquiry program on laboratory skills, science process skills, and understanding of science knowledge in middle grade students. (ERIC Document Reproduction Service No. ED 307 148)

Mensch, D. C. & Rubba, P. A. (1989). A study of large hands-on protein synthesis models on the biology achievement and attitude toward biology of students. Master Thesis, Pennsylvania State University. (ERIC Document reproduction Service No. ED 309 052)

Mitchell, T.J. (1989). What do instructors expect from beginning chemistry students. *Journal of Chemical Education*, **66**(7), 562-564.

Rust, F. O'C. (1994). The first year of teaching: It's not what they expected. *Teaching and Teacher Education*, **10**(2), 205-217.

Thompson, A.G. (1984). The relationship of teachers' conceptions of mathematics and mathematics teaching to instructional practice. *Educational Studies in Mathematics*, **15**(2), 105-127.

Yager, R.E. (1986). What's wrong with school science? *Science Teacher*, **53**(1), 145.

初任化學教師及其學生對科學教學的概念

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摘　　要

本研究探討了初任化學教師們在第一年的教學中對科學教學的概念之變化情形，並且比較了這些教師及他們的學生對科學教學的概念之差異性。由學年初及學年末的問卷調查比較中發現，這些初任教師與他們的學生，在優良教師必備條件的看法方面非常不同。同時，研究結果顯示，由於這些學生對科學教學的很多概念在這一年中幾乎沒有改變，因此看來似乎是這些初任化學教師調整了他們的概念以便適應其工作環境。另外，在有關學生動手做實驗的教學效果這方面的看法上，這些初任化學教師顯然比這些學生較不信服此教學效果。而且學生做實驗的次數，第二學期少於第一學期。因此若想發揮實驗的教學效果，宜透過各種努力，加強初任化學教師在實驗室教學方面的信心及意願。

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Preservice Teachers' Conception and Use of Laboratory Teaching Skills

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ABSTRACT

The purpose of this investigation was to assess the effectiveness of a field-based practice in promoting the development of effective laboratory teaching skills. The sample consisted of 10 preservice physics teachers (6 female, 4 male) completing their final year of teacher preparation. All of the preservice teachers were enrolled in a practicum which required the implementation of two one-hour laboratory activities in a public school setting, and were concurrently enrolled in microteaching and secondary science method courses.

Each of the preservice teachers was asked to plan and present a laboratory activity during the first two weeks of the Fall semester. Each preservice teacher completed a questionnaire concerning their conceptions/attitudes toward the planning, implementation, and evaluation of laboratory activities and a self-critique of their own lesson. During the next 10 weeks, the preservice teachers were provided with formal instruction on the planning and implementation of laboratory activities. Each preservice teacher then planned and implemented a second laboratory activity, which was again followed by a questionnaire, a self-critique, and a follow-up interview.

Qualitative analyses revealed that these preservice teachers spent an inordinate amount of time on pre-lab instructions and tended to implement laboratory activities which were highly structured and of the "verification/cookbook" variety. Follow-up interviews clearly indicated that these teachers, although supportive of an inquiry approach, were primarily influenced by their concern for classroom management. Prior research strongly supports the notion that preservice teachers focus primarily on classroom management and the results of this investigation clearly show how such concerns for "survival" (so commonly found in the preservice teacher) serve to compromise instruction and the teachers' beliefs.

Key words: preservice teacher; laboratory instruction; science teaching.

I. Introduction

Laboratory work has long been regarded as an integral and necessary aspect of the learning experience in science courses (Blosser, 1981; Hofstein, Ben-Zvi, & Samuel, 1976; Kyle, Penick, & Shymansky, 1979). Laboratory activities which accurately portray the nature of science and directly involve students with scientific processes continue to be a focal point of the advocated reforms for science instruction (Collette & Chiappetta, 1984). Furthermore, Kempa & Diaz (1990) proposed that practical work in science can be used to motivate students to learn science. However, the laboratory activities used in school science are not at all similar to actual scientific laboratory work. According to the 2061 Benchmarks (1993), several serious problems currently

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exist within laboratory activities as presented in K-12 instruction:

> the question to be investigated is usually provided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual). ... the correct answer is known ahead of time.

Therefore, it is not surprising that preservice teachers do not typically exhibit the planning and organizational skills necessary for the successful and safe implementation of laboratory activities. Interest in preservice teachers' knowledge of subject matter has gained renewed emphasis with current attempts to increase the quality of teacher education programs (Gess-Newsome& Lederman, 1990; Lederman & Gess-Newsome,; Gess-Newsome & Lederman, 1993). However, the manner in which college science courses are taught and presented with discrete, fragmented content seems inconsistent with current recommendations for secondary science instruction. It is too optimistic to think that preservice teachers can automatically integrate, synthesize and apply the knowledge they receive from teacher education programs into their classroom teaching. Krajcik and Borko (1991) also stated that pedagogical content knowledge is a teacher's understanding of how to teach a particular concept. The authors of emerging research concerned with pedagogical content knowledge appear to place high value on integrated knowledge (Lederman, Gess-Newsome, & Latz, 1993). Therefore, it is important to provide preservice teachers opportunities to reorganize knowledge from several domains including subject matter knowledge, general pedagogical knowledge, and other content knowledge.

The microteaching course continues to be an indispensable approach in the preservice education of science teachers. However, the effects of such a course on preservice teachers' thinking and teaching techniques relative to laboratory instruction has not been systematically investigated.

Although science preservice teachers think that conducting laboratory activities is very helpful for science learning, the aims of laboratory work in the eyes of different preservice teachers may be different according to their personal learning experience, preferences, and academic background. Above all, how preservice teachers relate their views of laboratory instruction to their classroom practice should be corroborated by implementing classroom observations, interviews, and questionnaires concerning their conceptions/attitudes toward the planning, implementation, and evaluation of laboratory activities.

The purpose of this investigation was to answer the following questions: (1) What do preservice teachers think about laboratory instruction? (2) What is the relationship between preservice physics teachers' conceptions of laboratory instruction and actual classroom practice? The results of this study support the effectiveness of a field-based practicum in promoting the development of effective laboratory teaching skills.

II. Methods

1. Sample

The sample consisted of 10 preservice physics teachers (6 female, 4 male) completing their final year of teacher preparation. All of the preservice teachers were enrolled in a practicum which required the implementation of two one-hour laboratory activities in a public school setting, and also concurrently enrolled in microteaching and secondary science method courses. All teachers had already taken required courses such as the fundamentals of education, educational psychology, educational technology, and principles of instruction. These students had also previously taken courses in general physics, electricity and magnetism, optics, and modern physics labs. However, they did not have any experience teaching laboratory activities.

2. Data Collection

Each of the preservice teachers was asked to plan and present a laboratory activity during the first two weeks of the Fall semester in 1992. These laboratory classes were observed (and videotaped) by the researcher and written feedback was provided. A global scan technique (Acheson & Gall, 1987) was used to supervise each preservice teacher's classroom teaching. Immediately following the completion of the laboratory lesson, each preservice teacher completed a questionnaire concerning their conceptions/attitudes toward the planning, implementation, and evaluation of laboratory activities and performed a self-critique of their lesson while viewing their teaching on videotape. The questionnaire responses, self-critique, and researcher's written feedback were discussed in a 40 minute follow-up interview. During the next 10 weeks, the preservice teachers were provided with formal instruction on the planning and implementation of laboratory activities. Numerous modeled laboratory and debriefing sessions, pre-lab instructions, post-lab discussions, activity management tasks, monitoring of students' thought processes, inductive and deductive tasks, and safety were discussed as part of the students' formal instruction concerning laboratory activities. Even though these preservice teachers had done quite a few science labs while completing the teacher education program, they may not have had a chance to do labs while thinking how to teach laboratory activities. It was arranged for each preservice teacher to do four different laboratory activities individually. Two of the four labs were categorized as verification labs, and the other two were thought of as inquiry-oriented labs. Each preservice teacher then planned and implemented a second laboratory activity which was observed and videotaped by the researcher, and again followed by a questionnaire, a self-critique, follow-up interview, and group discussion.

3. Data Analysis

This investigation was conducted employing a qualitative research methodology. A detailed, systematic analysis of preservice teachers' self-critiques, questionnaire responses, interviews, group discussions and classroom observations was performed by researchers in an attempt to derive any evident patterns in subjects' thinking and skills of laboratory instruction. The specific guidelines as presented by Bogdan & Biklen (1982) were followed. In particular, each researcher independently and systematically analyzed the transcripts of interviews and group discussions, questionnaire responses, and field notes of classroom observations. An initial analysis of the transcripts of interviews enabled one of the researchers to derive categories of the objectives of laboratory activities for the learning physics of junior high students. This process involved the coding of responses into apparent categories. The validity of these results were determined by comparing these categories with the views which were derived from the preservice teachers' self-critique comments, questionnaire responses, and group discussions. Given the nature of this analytical procedure, the researcher must protect him/herself from the identification of categories which are not representative or descriptive of the total data set. Consequently, each researcher repeated the process independently several times in an effort to refine derived categories and eliminate overlap between such categories. During the final analysis the two researchers worked together. The purpose was to further refine derived categories and resolve any discrepancies between the findings resulting from independent analysis.

III. Results and Discussion

The major results were organized in terms of the initial objectives guiding this investigation.

1. What do preservice teachers think about laboratory instruction?

Responses of different kinds of data gathering indicated that all preservice teachers could describe the importance and use of laboratory activities in teaching junior high physical science courses. Three major uses of laboratory activities were often mentioned by these preservice teachers. First, laboratory activities could assist students in learning science concepts. Laboratory activities also can provide students with an opportunity to practice manipulative skills. Lastly, students can learn how to solve problems by means of laboratory activities. Most preservice teachers agreed:

> "Laboratory work can provide students with hands-on activities. Students can learn science through manipulating with hands-on activities. Students can learn science through manipulating equipment and materials. The interest and enjoyment of learning science will surely be enhanced and the importance of doing laboratories to help students is unquestionable."

Although the adequacy of the declarative knowledge of these preservice teachers is satisfactory, the discrepancy between "knowing" and "doing" needs to be discussed. Most of the preservice teachers thought lecturing was much easier than providing students with laboratory activities. These preservice teachers said:

> "The instructional use of laboratory activi-

> ties is more costly than lecturing because of the equipment and supplies that are needed."

Such added expenses clearly influenced teachers' decisions concerning the use of laboratories as well as the planning of such activities. Furthermore, preparation for each laboratory activity was often inadequate and the necessary procedures, techniques, and skills needed for successful completion of the laboratory were not carefully practiced in advance. In short, most preservice teachers did not have enough procedural knowledge to teach laboratory activities. Stofflett (1994) mentioned that the majority of teacher candidates experience only didactic science pedagogy in their schooling, and their conceptions of science teaching are primarily didactic. This may influence preservice teachers' learning of new teaching strategies. In order to enhance the interest of teaching science by laboratory activities, preservice teachers need to be offered more opportunities to learn and practice the declarative knowledge which relates to laboratory instruction.

2. What is the relationship between preservice physics teachers conceptions of laboratory instruction and the act of teaching?

Preservice teachers showed passive and traditional attitudes toward the planning of laboratory instruction. While the adequacy of the equipment in any particular laboratory is a problem, the responsible, enthusiastic preserviceteachers should make an effort to gather any available materials for the purpose of carrying out the objectives of laboratory instruction. However,preservice teachers tended not try different ways of doing laboratory activities, and instead preferred to lecture. So, when the necessary equipment was not really available, laboratory instruction was not pursued.

It is not uncommon to observe preservice teachers making mistakes while providing laboratory instructions or interpreting data. For example, in one laboratory activity called the "Measurement of Iron Density," the only method identified to measure the volume of an iron cube was the displacement method. In fact, there are many ways to measure the volume of an iron cube. Unfortunately, given the size of the iron cube used, this particular method was the most inaccurate. Students were instructed to draw two lines on the side of a water-filled beaker before and after putting an iron cube in the beaker. The change of water level was used to measure the volume of the iron cube. However, the size of iron cube was very small and the volume of the beaker was too large for measuring the amount of water displaced by such a small cube. No alternative approaches were tried or suggested by the preservice teacher.

A second preservice teacher attempted to analyze the relationship between weight and the length change in a spring. After she put the "x"and "y" axes on the board, she then drew a straight line in the figure. As a matter of fact, a straight line is only true within the shorter rangeof changes in the spring. However, this preservice teacher thought $F=-KX$ could be obtained for the whole range from the limited data.

Furthermore, the performance of preservice teachers in laboratory teaching was unstable. The teaching skills of these preservice teachers were not displayed consistently during two implementations of laboratory activities. Preservice teachers tended to tell students too much in the pre-lab period. They also did not provide students with any opportunities to discuss or solve problems within groups. Instead, preservice teachers often responded to students' questions by giving them the answers. The lack of planning often led to students' confusion.

Qualitative analyses revealed that the preservice teachers had developed a healthy respect for the importance of pedagogical skills by the time they had completed their second laboratory lesson. Prior to receiving actual classroom experience, they possessed relatively simplistic views of classroom life and primarily focused on subject matter. Although the importance of pedagogy increased for them, it did not result in the inquiry-oriented laboratory instruction so often advocated in preservice courses and science teaching curriculum reforms. Rather, the preservice teachers spent an inordinate amount of time on pre-lab instructions and tended to implement laboratory activities which were highly structured and of the "verification/cookbook" variety. Follow-up interviews clearly indicated that these teachers, although supportive of an inquiry approach, were primarily influenced by their concerns for classroom management. Prior research (Costenson & Lawson, 1986; Sanford, 1984) strongly supports the notion that preservice teachers focus primarily on classroom management (Kagan, 1992), and the results of this investigation clearly show how such concerns for "survival" (so commonly found in the preservice teacher) serve to compromise instruction and the teachers' beliefs.

VI. Implications for Science Teacher Education

As a consequence of competitive university entrance examinations, preservice teachers should have strong content knowledge in their intended teaching areas. However, students in teacher education colleges are not normally offered experiences such as field practicums and student teaching which are focal points in U.S. teacher education programs. The critical point is that teacher education college graduates become science teachers without having a teacher certification examination. Before becoming beginning teachers, the sole teaching experience of these preservice teachers is one month of student teaching. Additionally, the feedback received during student teaching is very superficial. Most of the teachers begin to desire and try to become effective teachers after they have graduated from teacher colleges. Fortunately, a new law for educating teachers will be carried out in the near future. All prospective teachers will need to pass a certification examination. This requirement will considerably elevate the motivation of most of preservice teachers.

It is believed that a teacher needs to possess different kinds of abilities such as demonstration, manipulation, presentation, and classroom management in carrying out laboratory activities. In addition, the noise level of laboratory classrooms often interrupts the preservice teacher. Students may not learn anything from the laboratory activities if the students cannot work together within groups. Cohen (1991) suggested that if this more complex setting was to be effectively managed, it would be necessary to delegate more authority to students. During laboratory activities, the teacher should change from the authoritative role to a more student-centered and facilitative management approach. Programs which can allow preservice teachers to learn how to teach laboratory activities effectively should be systematically organized.

There is clearly a need to provide preservice teachers with more opportunities to construct meaningful conceptions of subject matter and the role of laboratory instruction. Stofflett (1994) designed a teaching model for preservice elementary teachers to enhance their knowledge of science pedagogy. Perhaps this particular model may help preservice teachers establish more functional and effective views of the use of laboratory activities.

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References

Acheson, K. A., & Gall, M. D. (1987). *Technique in the clinical supervision of teachers: Preservice and inservice applications* (2nd ed). NY: Longman.

Blosser, P.E. (1981). *A critical review of the role of the laboratory in science teaching*. Columbus: ERIC for Science, Mathematics, and Environmental Education, Ohio State University.

Bogdan, R .C., & Biklen, S. K. (1982). Qualitative research for education: An introduction to theory and methods. Boston, MA: Allyn and Bacon.

Cohen, E. G. (1991, April) *Classroom management and complex instruction*. Paper prepared for presentation in the SIG/M Classroom Management Invited Symposium, "Classroom Management Research: Expanding the Perspective", at the annual meeting of the American Educational Research Association, Chicago.

Collette, A. T., & Chiappetta, E. L. (1984). *Science instruction in the middle and secondary schools*. St.Louis, Missouri: Times Mirror/Mosby College.

Costenson, K., & Lederman, A. E. (1986). Why isn't inquiry used more in classroom? *The American Biology Teacher*, **48**, 150-158.

Gess-Newsome, J., & Lederman, N. G. (199). The preservice microteaching course and science teachers' instructional decisions: A qualitative analysis. *Journal of Research in Science Teaching*, **27**(8), 717-726.

Gess-Newsome, J., & Lederman, N.G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Education*, **77**(1), 25-45.

Hofstein, A., Ben-Zvi, R., & Samuel, D. (1976). The measurement of the interest in and attitudes to laboratory work among Israeli high school chemistry students. *Science Education*, **60**(3), 401-411.

Kagan, D. M. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research*, **62**(2), 129-169.

Kempa, R. F., & Diaz, M. M. (1990). Students' motivational traits and preferences for different instructional modes in science education-Part 2. *International Journal of Science Education*, **12**(2), 205-216.

Krajcik, J. S., & Borko, H. (1991). *Pedagogical content knowledge: An important construct for science educa-*

tion. Papers presented at the 64th annual meeting of the National Association for Research in Science Teaching.

Kyle, W. C., J., Penick, J. E., & Shymansky, J. A. (1979). Assessing and analyzing the performance of students in college science laboratories. *Journal of Research in Science Teaching*, **16**(6), 545-551.

Lederman, N. G., & Gess-Newsome, J. (1991). Metamorphosis, adaptation, or evolution? Preservice science teachers' concerns and perceptions of teaching and planning. *Science Education*, **75**(4), 443-456.

Lederman, N. G., Gess-Newsome, J., & Latz, M. (1993). *Becoming a teacher; Balancing conceptions of subject matter and pedagogy*. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, Georgia.

Sanford, J. P. (1984). Management and organization in science classroom. *Journal of Research in Science Teachig*, **21**(6), 575-587.

Stofflett, R. T. (1994). The accommodation of science pedagogical knowledge: The application of conceptual change constructs to teacher education. *Journal of Research in Science Teaching*, **31**(8), 787-810.

職前科學教師實驗教學能力培養之研究

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摘　要

本研究係採用質的研究法，意欲探求職前教師對於實驗教學的認知及其實驗室教學的實際表現。經由八十一學年度第一學期「科學教育專題研究」課程，每週二小時的施教，針對彰化師大物理系十位四年級的學生，進行數據的收集與系統的分析及解釋。每位職前教師必須進行二次試教，每次試教並予錄影，職前教師且必須進行自我評鑑及塡寫問卷。並針對試教現場記錄、試教錄影帶、與學生面談、集體討論、學生自我評鑑及塡寫問卷進行資料分析及找尋所呈現的職前教師對於實驗教學的認知與實際表現的明顯型態。

研究結果顯示，職前教師認爲實驗教學可以提供國中學生經由動手操作進行科學概念的學習、操作技巧的訓練、及發展學生的思考技能。大多數的職前教師皆能肯定探究式實驗教學的重要，然而，由於考慮學生的學習能力及班級管理，鮮少能進行探究式的實驗教學。甚且，實驗的進行方式常受限於可用的時間、所能提供的器材及教科書所明示的步驟與內容。即使職前教師在試教之前傾向於認爲國中物理實驗教學並不難教，可是，在試教之後的面談又認爲實驗教學比想像中的困難。更由於無法掌握學生做實驗的進度與時間的使用，這些職前教師認爲實驗教學與演講式的教學有很大的不同。綜合而言，職前教師對於實驗教學，仍僅止於「理論」上認知的程度，並未達「實踐」的程度。

在職前師資培育階段，若能增加實驗教學的試教次數及建立合適的實驗教學課程，對於職前教師實驗教學能力的訓練與成長，應是可行的途徑。

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A Learning System For Correcting Misconceptions in DC Electric Circuits

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ABSTRACT

This paper explores the construction of a scenario-based learning system for correcting students' misconceptions in the domain of DC electric circuits. The rationale of this corrective learning system is founded on the theories of mastery learning and elaborated corrective feedback. Our system can be also viewed as a computer implementation of mastery learning theory for the domain of DC electric circuits. The system has been evaluated for effectiveness and the results are positive and encouraging.

Keywords: Corrective learning, misconception, mastery learning theory, and corrective feedback.

I. Introduction

Throughout the learning progress, students may perform not as expected due to many reasons and therefore some deficiencies in knowledge are formed. These deficiencies can be categorized into the three types of discrepancy, uncertainty, and incompleteness. While both deficiencies of uncertainty and incompleteness in knowledge can be addressed by remedial instruction, basic discrepancies must be corrected. Otherwise such discrepancies in knowledge will result in misconceptions that may form a serious barrier to the students' learning progress. Once misconceptions in a certain knowledge domain are formed, how to diagnose and to correct these misconceptions are of important to students' learning.

In the past decades, many systems [2, 3, 4, 10, 11] had been developed in order to diagnose students' misconceptions, but very few studies addressed the issue of correcting misconceptions. Because misconceptions in students' knowledge cause such serious learning problem, we cannot only address the diagnosis while ignoring follow-up corrective work. Once a student's misconception in a certain knowledge domain has been identified, he or she should immediately be provided with an appropriate correcting procedure. Some previous research, such as WHY[13] and BUGGY[4], had implicit functions similar to correction. WHY is a tutoring system for instructing students about the reasons of rainfall using an interactive form of Socratic dialogue. BUGGY is an arithmetic tutoring system for diagnosing students' bugs in subtracting skills. But, although the process of dialogue or diagnosis exhibits effectiveness in correcting students' misconceptions, their corrective correction is only a by-product.

The tasks of misconception diagnosis and correction are complementary each other. Many existing systems can be used to diagnose misconceptions in students' knowledge. If computer-based corrective work could be performed, students' learning performance would be improved.

We have developed a corrective learning system that is based on scenarios. These scenarios are designed according to an analysis of students' misconceptions in knowledge. Each corrective scenario is for a primitive misconception. Once students' misconceptions have been diagnosed, we apply the corrective procedure on the students by proposing appropriate corrective scenarios. Through the learning of scenarios, the students can correct their misconceptions and learn correct concepts.

A corrective scenario can be an explanation about what an answer should be, a series of demonstrations, a dialectical dialogue, or even a story. The design of complicated scenarios may be needed to correct misconceptions in complex knowledge, such as knowledge of arithmetic procedures. However, because the knowledge of basic DC electric circuits addressed in our study is factual, we use demonstrations and explanations as our design criteria of scenarios.

We only address misconception correction here but not diagnosis, and we assume that the student's misconceptions have been diagnosed and are available in a student model. On the basis of this assumption, we can focus on the exploration of misconception correction while ignoring how these misconceptions were diagnosed.

Among the following sections, in Section 2 we first present an example of performing a corrective process, and in Section 3 we present the bases of our corrective learning system, including mastery learning theory and elaborated corrective feedback. Section 4 introduces the design of our scenario-based corrective learning system, including analysis of misconceptions, design of corrective scenarios, and construction of the corrective learning system. An evaluation of the system is given in Section 5, and conclusions and future works are discussed in Section 6.

II. Corrective Learning Process

The corrective learning process in our system is shown in Figure 1. The learning procedure is based on mastery learning theory as presented in Section 3.1. A student is first presented a general common sense instruction about a specific concept and then a pretest is conducted. If the student passes, no corrective activity is needed. If the student fails, he/she might have certain misconceptions about the topic. A corrective activity is necessary to help he/she correct that misconception.

During corrective feedback, an elaborated corrective fashion is adopted for corrective activity, i.e. the corrective scenario not only tells the student whether his/her answer is correct or incorrect, but also tells he/she why his/her answer is wrong, thus pointing out a way to solve the problem. A discussion of elaborated corrective feedback will be given in Section 3.2.

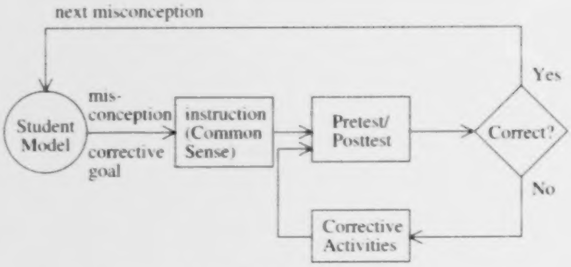


Fig. 1. Flow chart of the corrective learning process.

A posttest is taken after the corrective process, when the student should have corrected his/her misconception. If the student passes, then he/she has completed this corrective activity and the misconception has been corrected.

The corrective learning process continues until all scenarios concerning possible misconceptions in the student model have been answered correctly. The corrective process begins with the selection of a first misconception from the student model. All the misconceptions in the student model are presented to the student, and he/she can start with any one of his/her misconceptions to perform the corrective process. The screen of selecting a misconception is shown in Figure 2. Once the student has selected a misconception, the system will present the student with corresponding corrective scenarios. For example, the two corrective scenarios shown in Figures 3 and 4 are for the misconception of "voltage existence".

The circuit in the scenario illustrated in Figure 3 is not a closed loop. The bulb can't be lit up. However, there actually is a voltage existing in this circuit. If the power supply is a normal AC 110V electric source, touching any part of the circuit might cause a dangerous electric shock. Such an explanation can correct the misconception that no voltage exists in the circuit when the bulb is not lit. In the case of another corrective scenario illustrated in Figure 4, there is no power supply for this circuit. The bulb can't light up in this case, either. The explanation is that there is no voltage existing in this circuit because there is no electric source connected to it, i.e. the case of voltage-free only holds in the case of source-free. This scenario

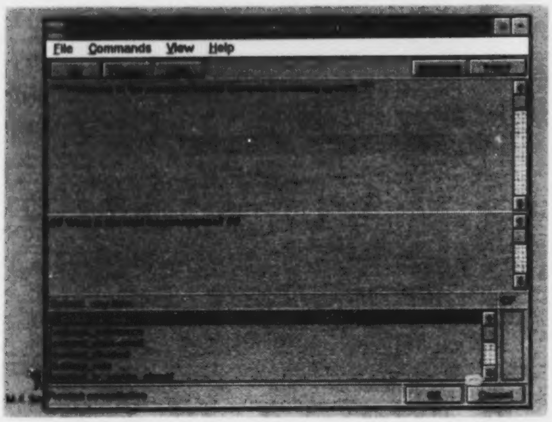
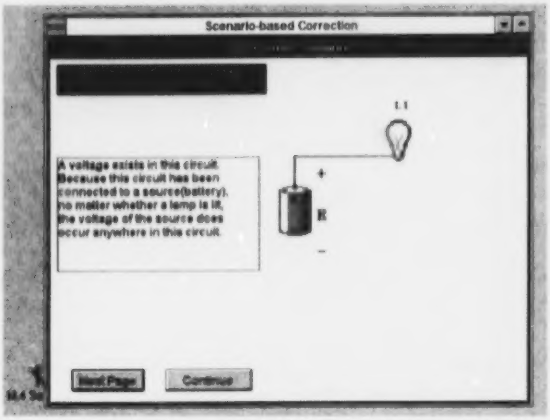
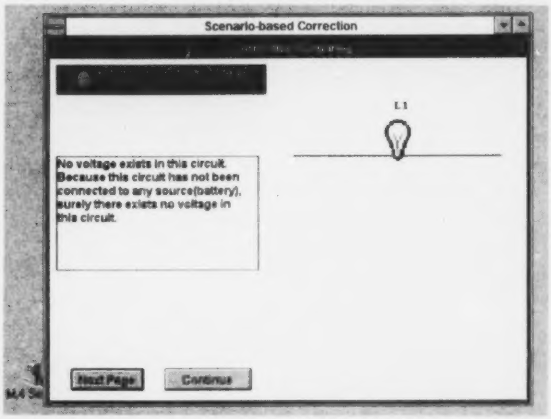


Fig. 2. Selecting the first misconception from the student model.



A voltage exists in this circuit.
Because this circuit has been
connected to a source(battery),
no matter whether a lamp is lit,
the voltage of the source does
occur anywhere in this circuit.

Fig. 3. Corrective scenario (1) for voltage existence.



No voltage exists in this circuit.
Because this circuit has not been
connected to any source(battery),
surely there exists no voltage in
this circuit.

Fig. 4. Corrective scenario (2) for voltage existence.

shows another "no lighting" case, but this case is voltage-free.

In these two scenarios we use the forms of demonstration and explanation to correct the misconception "voltage existence". For a domain of factual knowledge such as basic DC circuits, we show that this is a simple but effective fashion for the design of corrective scenarios.

After a misconception has been corrected, the system will show the result of the correction and prompt for selection of the next misconception. The misconception that has just been corrected is automatically removed from the student model. The corrective learning process will continue and repeat, each cycle for correcting a misconception, until all of the misconceptions within the student model have been corrected.

III. Rationale

In the corrective learning procedure described above, two theories of mastery learning theory and elaborated corrective feedback are used to design learning control and corrective activities. In the following subsections we will address these theories.

3.1 Mastery Learning Theory

Master learning theory was first proposed by Dr. Benjamin S. Bloom [1]. Bloom outlined a learning strategy as shown in Figure 5. In this strategy, the material to be learned over a term or semester is first divided into smaller learning units, and after the material from a unit is taught, a test is taken by the teacher to check on students' learning performance. This test provides a check on learning progress to that point, and is designed to provide precise feedback to both the teacher and the student about what has been learned well and what has not been learned well. Bloom believed that

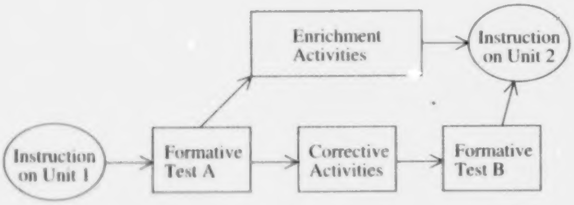


Fig. 5. Instruction process under mastery learning (Guskey 1985).

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checking on students' learning progress should be used not only to certify competent learners, but also to diagnose individual learning difficulties (feedback) and to prescribe specific remediation procedures (correction).

Students who have not mastered the material in a learning unit will be engaged in corrective work. After corrective work, they are provided with a second test to assure that they have mastered the material in the unit before moving on to the next learning unit. Some of the students will show on the test that they have already mastered all the material in the learning unit. For these students, special enrichment activities may be provided so that they can extend their original learning. In 1990, T. R. Guskey and others [8, 9] applied mastery learning theory to both regular and special education students. Their report showed that the use of mastery learning significantly increased student achievement for both regular and special education students.

In our system, the corrective learning procedure is based on mastery learning theory. It involves a formative evaluation (pretest) after initial instruction followed by corrective activities and reevaluation (or posttest).

3.2 Elaborated Corrective Feedback

The role of corrective activity in the corrective learning process shown in Figure 1 is to provide feedback to students for correcting misconceptions. This feedback is called corrective feedback and is needed when a misconception is diagnosed. Corrective feedback is divided into three methods as follows [6]:

(1) Minimal feedback: just telling students whether their answers are correct or incorrect.
(2) Basic feedback: telling students whether their answers are correct, and, if incorrect, supplying the correct answer.
(3) *Elaborated corrective feedback*: telling students whether their answers are correct, and, if incorrect, supplying the correct answer and providing additional information about the correct answer.

An experimental study concerning which one among these three types of feedback is the best one was performed by M. Collins and others [6] in 1988. The study compared the effects of elaborated corrective feedback and basic feedback in teaching remedial and learning disabled students at the high school level. They selected a cognitive task, formal logic, as the knowledge domain. The reason for this is that formal logic is a relatively complex and is generally lacking in curricula for both regular and special education students in elementary and junior-high school. Collins' study examined if low-performance students receiving elaborated correction procedures would perform significantly better than the ones provided with basic corrections. The result showed that elaborated corrective feedback is superior to the other types of feedback. According to this result, we have adopted elaborated corrective feedback as the basis of our corrective procedure. Within the corrective activities of the mastery learning process, the design rationale of our scenarios is the elaborated corrective feedback.

IV. Construction of A Corrective Learning System

4.1 Outline of the System

The block diagram of our scenario-based corrective learning system is shown in Figure 6. The modules in the system are described as follows.

1) Scenario Base: This contains all the corrective scenarios designed for correcting students' misconceptions. It is coordinated with the inference engine so that a domain expert module is formed.
2) Corrective Controller: This module is designed for retrieving appropriate corrective scenarios in order to correct specific misconceptions. It also controls the progress of the whole corrective procedure. The corrective controller is based on the mastery learning theory, i.e. it controls the process of corrective learning so that the students can attain the goal of mastery.
3) Student Model: The student model in our sys-

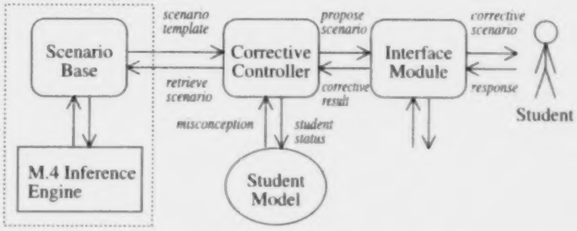

Fig. 6. Outline of the scenario-based corrective learning system.

tem is simple and only contains the students' misconceptions.

4) Interface Module: The interface module is an important feature in our system. How to make the corrective scenario lively and attractive is an important design criterion.

Figure 6 also illustrates the relationships among these four modules. Initially, the corrective controller retrieves a misconception from the student model. As corrective learning begins, the domain expert module provides the corrective controller with a scenario template that is then converted by the corrective controller, and is finally instantiated as a real corrective scenario by the interface module and presented to the student.

In the other direction, the responses of the student during correction are also collected by the interface module. They are converted into the corrective results and are finally recorded in the student model. The corrective results in the student model can be used to evaluate the effectiveness of the corrective learning system.

In the corrective learning system, the design of scenarios is critical and depends on the analysis of misconceptions in the domain knowledge. Several scenarios are designed for correcting any one misconception. Therefore, the analysis of misconceptions and the design of scenarios are two critical issues in the proposed system.

4.2 Analysis of Misconceptions in DC Electric Circuits

Over the past decades, various studies on misconceptions of basic electricity have been made focussing on many aspects and generating numerous results. In the area of series circuits, Carlsen & Andre [5] have shown a developmental sequence of misconceptions about electric circuits. In addition to simple series circuits, a more general consideration of basic DC circuit configurations, including parallel circuits, was adopted in Dupin and Johsua's study [7]. Shipstone et al. [12] made a study of the understanding of basic electrical concepts by 15-17 year-old students in five European countries. According to these studies, we conclude all the results and reorganize as nine primitive misconceptions in the following:

(1) *Current existence*: The student believes that a single wire connection between a battery and a bulb will light up the bulb. But the student does not know that the existence of current is associated with the condition of closed circuit.

(2) *Voltage Existence*: A large number of pupils know that current only exists in a closed circuit, but they also believe it is the same for voltage.

(3) *Consumption of current*: The student believes that current flows around the circuit in one direction and becomes weakened as it goes so that the later circuit elements receive less current.

(4) *Division of current*: The student believes that current flows around the circuit in one direction and is shared equally by the circuit components, but is partially or completely used up in the circuit components.

(5) *Battery role*: The student believes that the battery is a "current reservoir" delivering a constant current whatever the circuit attached.

(6) *Current in series circuit*: Many students believe that currents are the same in two contrasting circuits while ignoring the doubled resistance in the series circuit.

(7) *Voltage in series circuit*: The student regards the voltage as the same as the current in the series circuit and guesses that all voltages acrossing components in the series circuit are the same.

(8) *Current in parallel circuit*: A large number of pupils believe that bulbs in parallel would shine less than a single identical bulb.

(9) *Voltage in parallel circuit*: The student believes that branch voltages in the parallel circuit are different.

4.3 Design of Corrective Scenarios

The corrective scenarios are designed according to the analysis of students' misconceptions as described above. While each corrective scenario targets a primitive misconception, each primitive misconception might have more than one corrective scenario. The design philosophy of our corrective scenarios is based on the assertion of elaborated corrective feedback, i.e. during the progress of a scenario, it not only tells students what the correct concept should be, but also tells them how this answer is derived.

The scenario base is essentially a rule base written in M.4 rule and procedure syntax. The M.4 is basically a "backward chaining" expert system development tool. In M.4, any consultation is launched from a specific goal. Multiple goals are permitted. In our knowledge base, a goal is a correction for a specific misconception. If a student has multiple misconceptions in his knowledge, we have to do multiple corrections, each for one misconception. Hence, in such a situation, we have multiple goals to reach.

There are nine groups of rules in our scenario base corresponding to the nine misconceptions in basic electricity. These rules look very simple and similar, and are just scenario templates. Each scenario template will invoke a M.4 procedure that can be instantiated in the interface module for presenting corrective demonstrations or explanations. For example, the explanations of correcting the misconception "voltage existence" are shown in two scenarios of Figures 3 and 4. The explanation in Figure 3 is for correcting the misconception that the voltage acrossing two ends of a open circuit does not exist. The scenario of Figure 4 shows the concept that the case of voltage-free only holds in a circuit of source-free.

V. Implementation and Evaluation

The system is implemented under the Windows graphical environment on a generic PC platform. We adopted the expert system development tool M.4 to design the corrective scenarios. With M.4, we wrote a set of rules and procedures to form a scenario base. We also used Visual BASIC to write the corrective controller and interface module. The program size is now about 7500 lines.

In order to verify the pedagogical effectiveness of this corrective learning system, we have conducted a practical evaluation. The evaluation was based on the result of an experiment using our system with several groups of high school students. We selected high school students as our subjects because they had just learned the domain knowledge, basic electricity, in their physics course. We selected the students for our experiment from three senior high schools in Taipei.

We randomly selected two classes from each school, and randomly designated as a control group and another as an experimental group. For the first and the second senior high school, there are 8 effective samples in both control and experimental groups. For the third senior high school, there are 12 effective samples in both control and experimental groups.

Our experiment can be viewed as a computer implementation of the mastery learning theory in a specific domain. According to the mastery learning theory, students should be given a formative evaluation after initial instruction, followed by corrective activities and reevaluation.

In our implementation of the mastery learning theory by applying our corrective learning process on the subjects of the experimental group, the student first takes a pretest to check if he has some primitive misconceptions in the domain knowledge. For each misconception, a corresponding corrective activity is provided. After engaging in the corrective learning process, the student should have corrected his/her primitive misconceptions, and a posttest is immediately given to check the corrective performance.

In contrast with the experimental group, the subjects in the control group only take a posttest to check their misconception status. In other words, they accept only the regular initial instruction and are not exposed to the corrective learning process.

The experimental results in Table 1 show that the overall effectiveness of the corrective activity is very pronounced. For the control groups, less than 60%, or even less than 40%, of the students passed tests on each of the nine concepts. For the experimental groups, the improvement was dra-

Table 1. Experimental Result

No of	Control groups			Experimental groups		
Mis-conception	Test passed	Test failed	% of Passed	Passed or Corrected	Not corrected	% of Corrected
1	24	4	85.7	28	0	100
2	13	15	46.4	28	0	100
3	12	16	42.9	26	2	92.9
4	24	4	85.7	26	2	92.9
5	9	19	32.1	22	6	78.6
6	17	11	60.7	26	2	92.9
7	11	17	39.3	23	5	82.1
8	16	12	57.1	22	6	78.6
9	17	11	60.7	28	0	100

matic. Over 80% of the students passed the tests.

VI. Conclusions And Future Works

Our system is founded on the popular PC platform and runs under the graphical environment of Windows. It offers a user-friendly learning environment that can correct misconceptions in knowledge by using corrective scenarios. The designs of the corrective scenarios are based on an analysis of misconceptions in the domain knowledge. We have concluded the misconceptions in the topic of basic electricity. The corresponding scenarios are in the forms of explanations and demonstrations.

As a corrective learning system, our system can be also viewed as a computer realization of the mastery learning theory. Its goal is to help almost all students attain a mastery level in the domain knowledge with their misconceptions completely corrected and learning roadblocks totally excluded. The system has been successfully evaluated as effective for almost all of the students to help them reach the mastery level in their learning progress.

We have some tasks to do in the future to enhance our system capability and make the system more powerful. The tasks are outlined in the following:

(1) The first task is to extend the primitive misconceptions to compound misconceptions in the original knowledge domain. If it is proved OK, then we could expand the domain knowledge to other fields and test the corrective effectiveness.

(2) The student model in our system is rather simple. It could be enhanced such that the student feedback could be collected and the system could adapt the scenario in order to make a more accurate correction in the future.

(3) The design of scenarios in the system is for the factual knowledge. However, some knowledges, such as procedure or conditional knowledge, are different to the factual knowledge. These types of knowledges cannot be corrected only based on a series of demonstrations or explanations, the design of scenarios is based on other approaches, such as Socratic dialectics.

Acknowledgment

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References

Bloom B. S. (1971). Mastery Learning. In J. H. Block (Ed.), Mastery Learning: Theory and Practice. New York: Holt, Rinehart & Winston.

Brna P. and Caiger A. (1992). The application of cognitive diagnosis to the quantitative anaysis of simple electrical circuits. *In Proc.* of ITS-92, pp. 405-412.

Brown J. S. & Vanlehn K. (1980). Repair theory: a generative theory of bugs in procedural skills. *Cognitive Science*, **4**, pp. 379-426.

Burton R. R., Diagnosing bugs in a simple procedural skill. In Sleeman P. & Brown J. S. (Eds.) (1982). *Intelligent Tutoring Systems*, pp. 157-183. Toronto: Academic Press.

Carlsen D. D. & Andre T. (1992). Use of a Microcomputer Simulation and Conceptual Change Text To Overcome Student Preconceptions about Electric Circuits. *Journal of Computer-Based Instruction*, Vol. **19**(4), pp. 105-109.

Collins M., Carnine D. & Gersten R. (1988). Elaborated Corrective Feedback and the Acquisition of Reasoning Skills. A Study of Computer-Assisted Instruction. Reports.

Dupin J. & Johsua S. (1987). Conceptions of French Pupils Concerning Electric Circuits: Structure and Evolution. *Journal of Research in Science Teaching*, Vol. **24**(9), pp. 791-806.

Guskey T. R. (1985). Implementing Mastery Learning. Belmont, California: Wadsworth.

Guskey T. R. et al. (1990). Using Mastery in the Regular Classroom to Help Learning Disabled and At-Risk Students. Reports.

Hoppe H. (1994). Deductive error diagnosis and inductive error generalization for intelligent tutoring systems. *Jl. of Artificial Intelligence in Education* Vol. **5**(1), pp. 27-49.

Lee A. B. (1988). Computer-aided misconception-based intelligent tutoring and exercise generation. *Programmed Learning and Educational Technology*, Vol. **25**(1), pp. 67-73.

Shipstone D. et al. (1988). A study of Students' Understanding of Electricity in Five European Countries. *International Journal of Science Education*. Vol. **10**(3), pp. 303-316.

Stevens A., Collins A., and Goldin S. E. (1982). Misconceptions in student understanding. In D. H. Sleeman and J. S. Brown (Eds.). Intelligent Tutoring Systems, pp. 13-24, London: Academic Press.

一個以矯治直流電路中迷失概念為主之學習系統

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摘　要

本文探討一個矯治學習系統，該系統以情節爲導向，矯治直流基本電路之迷失概念。依據精熟學習理論與精確矯治回饋概念構置本系統。因此本系統可謂是精熟學理論在直流電路上的電腦應用實作。經過實測分析，本系統在矯治學習上確有效果。

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A Study of Children's Conceptions of Life, Animals, and Plants as well as Their Alternative Conceptions

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ABSTRACT

The purpose of this study was to explore children's concepts of life, animal, and plant as well as their alternative conceptions at the elementary school level. An oral interview research approach was adopted. The subjects were selected from three elementary schools in Taitung City, and three students in each grade at each school were interviewed and audiotaped. The findings of the study indicated that children used growth, nutrition, and reproduction as the criteria to differentiate living and nonliving things; and movement, trophic patterns, and the cell wall to discriminate animals from plants. Results also suggested that students subscribed to a highly restricted view of animals and plants, applying the terms almost exclusively to vertebrates and vascular or flowering plants.

Keywords: alternative conceptions, attributes, qualitative data

I. Introduction

As for the research on the development of children's concept of life, early in this century Piaget (1929) proposed "animism" to account for the fact that children often see inanimate objects as living things capable of sensations and feelings. On the basis of his interview data, Piaget identified four stages which characterized the development of the "life concept" in children: Stage 1: anything useful to man was considered alive. Stage 2: anything that moved was considered a living creature. Stage 3: anything showing spontaneous movement was considered alive. Stage 4: life was only attributed to plants and animals. Russell and Dennis (1939) also confirmed the four stages in their results. Furthermore, after reviewing the literature on animism, Looft and Bartz (1969) concluded that animistic thoughts pervasively exist among children of all ages and even among adults. Yet other studies have focused on characteristics of life other than spontaneous movement. For instance, Looft(1974) used the criteria of respiration, nutrient intake, and reproduction in studying the life concept of second graders. Similarly, Smeets (1973) investigated the attribution of death, growth, feeling, hearing, and talking to living and non-living objects.

The notion of animal is commonly used in biological texts and lessons and is also a basic concept in the study of biology or other life sciences. Because this concept is used so frequently, it is frequently assumed that students have the same concept of animal as that which is scientifically accepted by the biology community. In fact, not a few studies have shown that many children have alternative interpretations, be they termed preconceptions, misconceptions, naive knowledge,

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or alternative conceptions, of the concept of animal. For example, studies have supported that children have a concept of animal restricted to instances drawn predominantly from zoos, pets, and farm animals (Bell, 1981a; Bell and Baker, 1982; Trowbridge and Mintzes, 1985). As for the study of children's concept of plant, one finding of the in-depth interviews was that it appeared many students in science classrooms did not have a scientifically acceptable concept of plant (Bell, 1981b).

Since the three basic concepts of "life", "animal", and "plant" are so close to children's daily lives, and are central to all life science courses, undoubtedly it is important for science educators to be aware of students' concepts of life, animal, and plant and their alternative conceptions as well. Their common usage in science texts implies that chidren do have meanings or concepts to attach to these terms. But what concepts do students have, and how are they similar to the ones of specialists? This study tried to explore the following three problems:

1. The hierarchy of the development of children's concept of life.
2. The hierarchy of the development of children's concept of animal.
3. The hierarchy of the development of children's concept of plant.

II. Methods

1. Selection of subjects

The interviewed subjects were recruited from three elementary schools in Taitung City, which were located in an urban, suburban, and rural area respectively. Children of moderate scholatic achievement and fluent speaking ability were screened and selected to be the subjects through a simple pencil-paper test and their homeroom teachers recommendations. In total, fifty four (54) students, three (3) in each grade per school, were interviewed in this study.

2. Interview tasks

For the first task, the students were given a set of eleven objects and asked to sort the objects into living or nonliving things. In the second task eight living objects were presented and the students were asked to sort the objects into animals or plants. During the interview each student was asked to interpret and elaborate the reasons why the object was living or nonliving, animal or plant. Each student's interview varied in length, averaging some 25-30 minutes, and was conducted in the privacy of a small room. The responses of each interviewee were recorded in field-notes and audiotaped for analysis at a later time.

3. Data analysis

How do children differentiate between "alive" and "not alive" ? The following criteria were used to analyze the reasons which children used for their classification of living and nonlivng things:

(a) General life characteristics (Hopson and Wessels, 1990, pp.2-5: Starr, 1994, pp.3-7):
  1. Growth and Development,
  2. Nutrition,
  3. Reproduction,
  4. Compelx Organization,
  5. Responsiveness,
  6. Variety,
  7. Adaptation,
  8. Homeostasis .

(b) Other criteria (Lucas et al., 1979; Tamir et al., 1981; Trowbridge and Mintzes, 1985):
  9. Movement,
  10. Death, 11. Utility,
  12. Anthropomorphic,
  13. Habitat,
  14. Tautology.

To investigate students' reasons for differentiating plants from animals, the analysis was based on the following criteria for the concept of plant:

(a) General characteristics of plants (Hopson and Wessels, 1990, p. 389; Mader, 1990, p. 371):
  1. Movement,
  2. Autotrophic,
  3. Cell Wall,
  4. Alternation of Generations.

(b) Other criteria (Lucas et al., 1979; Tamir et al., 1981; Trowbridge and Mintzes, 1985):
  5. Viability,
  6. Growth,
  7. Vegetative Organs i.e., root, stem, leaf,
  8. Reproductive Organs i.e., flower, fruit, seed,
  9. Anthropomorphic,
  10. Habitat,
  11. Members of Group.

The following criteria were used to categorize the students' reasons for differentiating animals from palnts:

(a) General characteristics of animals (Hopson and Wessels, 1990, p. 410; Mader, 1990, p. 387):

1. Movement,
2. Heterotrophic,
3. Cell Wall,
4. Alternation of generations.

(b) Other criteria (Lucas et al., 1979; Tamir et al., 1981; Trowbridge and Mintzes, 1985):

5. Viability,
6. Growth,
7. Appendages,
8. Reproduction,
9. Body Temp. Regulation,
10. Noise Making,
11. Sensory Organs,
12. Cephalization with Head,
13. Excretion,
14. Anthropomorphic,
15. Habitat.

III. Results

When students were asked to sort objects into two classes of living and nonliving, there were few mental conflicts concerning objects which students were familiar with. But for objects with unfamiliar characteristics, such as coral, the data showed that even sixth graders still had difficulty in considering coral an animal. Interestingly, eggs and seeds, even though they belonged to animal and plant kingdoms respectively, were considered as not alive by many interviewees. Surprisingly, even sixth graders still had animistic ideas, so that sun was considered to be alive because "it can move" (Table 1).

Table 2 represents the distribution of reasons given during the classification task interviews for differentiating objects into living and nonliving classes. It is seen that growth and development are the most common criteria of life to be mentioned; nutrition (taking in and using energy) was next; reproduction was third. Apparently, the other five characteristics - complex organization, responsiveness, variations, and adaptation, and homeostasis were not used. It seems that elementary school students do not have such conceptual knowledge in their domain cognitive system.

Other criteria included incomplete conceptions, misconceptions or alternative conceptions of the "concept of life". In reality, movement is the general trait of animals during their life-span but not all living creatures could move freely. Death referred to the end of life processes and was the antonym of "living". Utility means being useful to people and there were obvious suggestions of animism in students' interpretation of "what is life?" (Piaget, 1929, pp. 196-199). As for anthropomorphism, typical arguments were that "it has soul, is conscious; it can speak; it feels like people", and no doubt these arguments were based on students' understanding of characteristics which were specific to human beings. Furthermore, the results showed that lower graders reflected more "tautological" thinking, such as "it is alive because it is a living creature". And a few 5th and 6th graders used "habitat" as an indicator to define "what is life?".

Generally as the grade went up, interviewees used more biological characteristics (items 1 to 3)

Table 1. Students' Response Frequency for Classification of Objects into Living or Nonliving Categories

Object	Grade											
	1st		2nd		3rd		4th		5th		6th	
	Liv	Non	Liv	Non	Liv	Non	Liv	Non	Liv	Non	Liv	Non
Gravel	1	8	0	9	0	9	0	9	0	9	0	9
Sun	3	6	2	7	1	8	1	8	2	7	1	8
Car	1	8	1	8	1	8	0	9	0	9	0	9
Rose	8	1	8	1	8	1	9	0	9	0	9	0
Palm	8	1	8	1	8	1	9	0	9	0	9	0
Cow	9	0	9	0	9	0	9	0	9	0	9	0
Fish	8	1	8	1	8	1	9	0	9	0	9	0
Earthworm	8	1	8	1	8	1	8	1	9	0	9	0
Coral	6	3	6	3	7	2	7	2	7	2	8	1
Seed	5	4	6	3	5	4	7	2	8	1	7	2
Egg	3	6	5	4	5	4	7	2	8	1	7	2

"Liv" means living creature. "Non" means inanimate object.

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Table 2. Distribution (Frequency) of Students' Reasons Used in Classifying Living and Nonliving

Criterion	Grade					
	1st	2nd	3rd	4th	5th	6th
Life traits						
Growth & Development	6	6	8	7	9	9
Nutrition	3	5	7	8	9	9
Reproduction	2	3	3	5	6	6
Complex Organization	0	0	0	0	0	0
Responsiveness	0	0	0	0	0	0
Variety	0	0	0	0	0	0
Adaptation	0	0	0	0	0	0
Homeostasis	0	0	0	0	0	0
Other Criteria						
Movement	9	9	9	9	9	9
Death	9	9	9	9	9	9
Utility	3	3	1	4	0	2
Anthropormorphic	1	0	1	2	2	1
Tautology	4	1	2	2	1	1
Habitat	1	0	0	1	1	1

and referred less to criteria (items 9 to 14) which are incompatible with experts' conception of life.

The results of the second interview task of classifying living objects into animals and plants (Table 3) indicated that interviewees had less dificulty in classifying common living creatures such as rose, palm tree, cow, fish, and earth worm. On the other hand, most children faced cognitive difficulty in considering coral an animal, but this trend decreased as age went up. Interestingly, even though the students were told just before the interview that coral is alive, over 20% of the interviewees still considered that coral was inanimate. In addition, the results showed that students had more difficulty in referring to an egg as an animal than referring to a seed as a plant, but this tendency declined as the grade went up.

The students' ideas for interpreting their conceptions of plants were categorized and shown in Table 4. The results revealed that all students considered a living creature a plant when it was immotile. It should not be surprising that none of the lower graders used autotrophic nutrition (photosynthesis) and cell walls as indicators, but more and more students used these two traits as the

Table 3. Students' Response Frequency for Classification of Living Objects into Animal or Plant Categories

Object	Grade											
	1st		2nd		3rd		4th		5th		6th	
	Ani	Pla	Ani	Pla	Ani	Pla	Ani	Pla	Ani	Pla	Ani	Pla
Rose	1	8	1	8	0	9	0	9	0	9	0	9
Palm	1	8	1	8	0	9	0	9	0	9	0	9
Cow	9	0	9	0	9	0	9	0	9	0	9	0
Fish	8	1	9	0	9	0	9	0	9	0	9	0
Earthworm	8	1	8	1	9	0	9	0	9	0	9	0
Coral	1	6	1	6	1	6	2	5	2	5	3	5
Seed	0	5	0	6	0	5	0	7	0	8	0	7
Egg	2	1	4	1	4	1	7	0	7	0	7	0

"Ani" means animal, "Pla" means plant.

Table 4. Distribution (Frequency) of Students' Criteria for Invoking the Concept of Plant

Criterion	Grade					
	1st	2nd	3rd	4th	5th	6th
Traits of Plants						
Movement	9	9	9	9	9	9
Autotrophic	0	0	1	2	5	7
Cell Wall	0	0	1	1	3	6
Alternation of Generations	0	0	0	0	0	0
Other Criteria						
Viability	1	2	0	0	1	1
Growth	3	2	4	5	3	3
Vegetative Organs	0	2	3	3	4	1
Reproductive Organs	0	0	1	3	2	1
Anthropomorphic	1	0	0	0	1	1
Habitat	1	2	1	0	4	2
Member of Group	2	1	1	3	2	1

grade elevated. And it is reasonable that none of the interviewees indicated the alternation of generations in their explanation of the plant concept.

Similarily, some students included alternative notions of the plant concept in their interpretation. For example "viability" and "growth" as the characteristics of life, and "vegetative organs" and "reproductive organs" as external features restricted to vascular or flowering plants. Compared with for animals, interviewees less often showed anthropomorphic thought, and less offen used "habitat" and "member of group" as indicators for explaining plants.

The results of students' interpretations for

Table 5. Distribution (Frequency) of Students' Criteria for Invoking the Concept of Animal

Criterion	Grade					
	1st	2nd	3rd	4th	5th	6th
Traits of Animals						
Movement	9	9	9	9	9	9
Heterotrophic	7	8	7	9	9	9
Cell Wall	0	0	1	1	3	2
Alternation of Generations	0	0	0	0	0	0
Other Criteria						
Viability	0	1	1	2	3	2
Growth	2	1	2	1	2	3
Reproduction	2	2	3	4	5	4
Appendages	2	3	6	3	1	5
Body Temp. Regulation	0	0	1	1	2	2
Noise Making	4	3	2	0	3	4
Sensory Organs	1	1	3	2	2	3
Cephalization with Head	0	2	1	0	2	3
Excretion	0	1	2	3	3	3
Anthropomorphic	3	2	0	1	3	2
Habitat	2	0	0	0	1	1

classifying living creatures into animals and plants are shown in Table 5. Movement was the most popular indicator for distinguishing animals from plants. The second indicator was that animals required heterotrophic nutrition, and having cells without cell walls was the third. Reasonably, alternation of generations did not appear in students' knowledge systems since there was no such content material in elementary school science.

When asked to define and elaborate the concept of animal, students identified a wide range of alternative attributes which were incompatible with the ideas of biologists. The first category was, as with conceptions of plants, to use life characteristics such as "viability", "growth", and "reproduction". The second one was conceptions restricted to certain species among the animal kingdom, such as "having appendages, head, sensory organs", "regulating body temperature", "noise making", and "excretion". It is understandable that more interviewees attributed anthropomorphic traits to animals than plants. In addition, habitat (animals live in the farm, woods, water,...) was also used as an indicator to identify animals.

IV. Discussion

The results shown in Table 2 shed light on some trends concerning the development of the concept of life. The use of biological characteristics, i.e. growth and development, nutrition, and reproduction as criteria increased from grade 1 to grade 6. These ideas had already been included in elementary school science and were most closely related to childrens' everyday life. These findings were consistent with the studies done by Smeets (1973; 1974). Movement was the most popular indicator, and in the biology community it is the general characteristic of the animal kingdom. However, the results in Tables 1 and 2 show that the importance of movement was de-emphasized in identifying living objects, and these findings matched the results of other studies (Looft, 1974; Looft and Bartz, 1969; Lucas et al., 1979). But animistic ideas still obstinately clung in the minds of some students. For example, one sixth grader ascribed life to the sun "because it moves", and this finding was the same as in Piaget's study (1929; p. 203). Death was also frequently used as a criterion and categorized as a biological reason in other studies (Tamir et al., 1981), but nevertheless, semantically, death is the antonym of living and means the ending of life. Other students' alternative conceptions of life found in this study were utility, anthropomorphic notions, tautology and habitat. These were almost the same as in other reports (Lucas, 1979; Tamir et al., 1981).

It was known that many students in science classrooms did not have a scientifically legitimate concept of plant (Lucas, 1981). In this study, interviewees used the external features which are specific to vascular or flowering plants to interpret the notion of plant. Similarly, not a few interviewees considered the traits restricted to some groups of animals as common attributes of the animal kingdom, and used these traits to interpret the concept of animal. Accordingly, these results seemed to verify Bell's comments that "There appears to be a common and scientific meaning of the word 'animal'. The common meaning appears to refer the restricted category of four-legged terrestrial mammals" (Bell, 1981a). According to the results in Tables 4 and 5, not a few students ascribed attributes to plants or animals that are common to all living creatures. Evidently there was considerable confusion between attributes of living things generally and those peculiar to the plant or animal kingdoms. This tendency was discovered almost a decade ago (Trowbridge and Mintzes, 1985; 1988). Other alternative conceptions of both plant and animal concepts, the same as with the concept of life, were tautology (viability), anthropomorphic notions, habitat and members of a group.

Certainly, although a scientist would not legitimately ascribe them to the concepts of life, plant, and animal, all the scientifically unacceptable notions mentioned previously were ubiquitous (Bell, 1981a; 1981b; Bell and Barker, 1982; Braund, 1991; Ryman, 1974; Tema, 1989; Trowbridge and Mintzes, 1985; Villalbi and Lucas, 1991). According to the tenets of constructivism, "Meaning is constructed by the cognitive apparatus of the learner" (Resnick, 1983), and a synthesis position of constructivism states that knowledge is personally constructed but socially mediated (Tobin and Tippens, 1993). Consequently, it is an inevitable phenomenon that children have alternative conceptions within their minds while they explore and try to recognize the world. Accordingly, the origin of the children's alternative conceptions about the concepts of life, plant and animal might be attributed to: 1) their immaturity of cognitive development, 2) lack of experiential konwledge in biological science; 3) social influences derived from peers, parents, media, other adults and even teachers.

V. Conclusions

The most important findings are summarized as follows:

(a) Students of elementary school level subscribed to a wide range of both scientifically acceptable and alternative conceptions of life, plant, and animal concepts.

(b) Elementary school children used growth and development, nutrition, and reproduction as common traits to differentiate living from nonliving objects. The other characteristics of life were never used as indicators to describe the concept of life. Often children had difficulty in considering dormant seeds and eggs as alive.

(c) Immotility was the most popular indicator used by all children in interpreting the concept of plant. More and more students used autotrophic nutrition and cells with a cell wall as indicators as grade level increased. None of the children mentioned the notion that the life cycle of plants proceeds through alternation of generations.

(d) In general, the development of children's conceptual knowledge of the concept of animal was under the hierarchial order of motility, heterotrophic nutrition, and cells without a cell wall.

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Reference

Bell, B. F. (1981a). When is an animal not an animal? *Journal of Biological Education*, *15*(3), 213-218.

Bell, B. F. (1981b). What is a plant?: Some children's ideas. *New Zealand Science Teachers*, *31*(1), 10-14.

Bell, B. F. & Barker, M. (1982). Towards a scientific concept of animal. *Journal of Biological Education*, *16*(3), 197-200.

Braund, M. (1991). Children's ideas in classifying animals. *Journal of Biological Education*, *25*(2), 103-110.

Hopson, J. L. & Wessells, N. K. (1991). *Essentials of biology*. New York: McGraw-Hill.

Looft, W. R. (1974). Animistic thought in children: Understanding of living across associate attributes. *Journal of Genetic Psychology*, *127*, 235-240.

Looft, W. R. & Bartz, W. H. (1969). *Animism revived. Psychological Bulletin*, *71*, 1-19.

Lucas, A. M., Linke, R. D. & Sedgwick, P.P.(1979). School children's criteria for alive : A content analysis approach. *The Journal of Psychology*, *103*, 103-112.

Mader, S. S. (1990). Biology. IA: Wm.C. Brown.

Piaget, J. (1929). *The child's conception of the world*. New York: Harcourt Brace & Workd.

Resnick, L. B. (1983). Mathematics and science learning: A new conception. *Science*, *220*(4595), 477-478.

Russel, R. W. & Dennis, W. (1939). Studies of animism: I. A standardized procedure for the investigation of animism. *Journal of Genetic Psychology*, *55*, 389-400.

Ryman, D. (1974). Children's understanding of the classification of living organism. *Journal of Biological Education*, *8*, 140-144.

Smeets, P. M. (1974) The influence of MA and CA on the attribution of life and life traits to animate and inanimate objects. *Journal of Genetic Psychology*, *124*, 17-27.

Starr, C. (1994). Biology: Concepts and applications. Belmont, California: Wadsworth.

Tamir, T., Gal-Choppin, R. & Nussinovitz, R.(1981). How do intermediate and junior high school students conceptualize living and nonliving? *Journal of Research in Science Teaching*, *18*(3), 241-248.

Tema, B. O. (1989). Rural and urban African pupils' alternative conceptions of animal. *Journal of Biological Education*, *23*(3), 199-207.

Tobin, K. & Tippins, D. (1993). Constructivism as a referent for teaching and Learning. in Tobin, K.(Ed.) The practice of constructivism in science education. Washington: The American Association for the Advancement of Science.

Trowbridge, J. E. & Mintzes, J. J. (1985). Students' alternative conceptions of animals and animal classification. *School Science and Mathematics*, *85*(4), 304-316.

Trowbridge, J. E. & Mintzes, J. J. (1988). Alternative conceptions in animal classification: A cross-age study. *Jorunal of Research in Science Teaching*, *25*(7), 547-571.

Villalbi R. M. & Lucas, A. M. (1991). When is an animal not an animal?: When it speaks English! *Journal of Biological Education*, *25*(3), 184-186.

國小學生的生命、動物、植物概念發展及另有構念研究

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摘　要

本研究是利用個別晤談法，來探究國小學生的生命、動物、植物概念發展情形，以及學生所持有的另有構念。晤談主體選自台東市三所國小的一至六年級學生，每一年級九人，一共54位學生接受晤談。質的數據經分析歸類後發現：國小學生只以生長、營養、生殖三種屬性來區別生物和非生物；以能否運動、營養型式、有無細胞壁三種屬性作爲分辨動植物的標準。同時，結果也顯示國小學生常以脊椎動物的特徵來描述動物概念；以維管束或顯花植物特徵來描述植物概念。

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PC-Assisted Electrostatic Instruction in an Introductory Electromagnetics Course

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ABSTRACT

To enhance undergraduate students' interest and efficiency in learning electromagnetics, an educational electrostatic software is proposed. This semi-interactive software deals with different charged capacitors, employs both rectangular and cylindrical coordinates in computation, and includes three different numerical methods for solving associated matrix equations. Some parameters in the program can be changed by students in order to investigate associated electrostatic problems that are difficult to handle through the traditional teaching process.

In this paper, this pedagogical program's design and some illustrative examples are described. Relevant concepts and students' responses are included and discussed in the illustrative examples. Also included in these examples is a time-efficiency comparision of the three numerical techniques for solving the derived matrix equation for a circular parallel-plate capacitor.

Key words: CAI, electrostatics, instructional material and technology

I. Introduction

In spite of its wide range of modern and exciting applications, electromagnetics has been considered a very difficult subject by undergraduate students, and the degree of student motivation to learn the subject matter of electromagnetics (EM) is one of the lowest among the areas of electrical and electronic engineering. The two main reasons for this situation are: (a) electromagnetic concepts are perceived to be abstract, and (b) every simple problem in EM must be treated by involved manipulative mathematics, often using strange and unfamiliar notations. With the advent of the personal computer (PC) on campus as a pedagogical tool, many studies concerning how to develope computer_aided instructional software to help undergraduate students learning EM have been carried out and reported (Broschat, 1993; Coren, 1993; David de Wolf, 1994; Hoburg, 1987, 1993;Iskander, 1988, 1991; Rao, 1990).

Present students were raised with television and strongly favor visual imagery for gaining comprehension over a more contemplative analytic approach. It is the experience of many faculties (Coren, 1993) that computer use raises the students' interest and understanding, and makes them more active learners and participants in all parts of the course. It is now almost imperative in some universities in America that all students of EM should have at least a passing familarity with computer computational techniques.

In developing and discussing importance concepts and formulas such as capacitance, resistance, and inductance in passive electromagnetic devices, some assumptions are often introduced in EM courses to simplify the approach, and the associated mathematic methods which are learned from these approximations are sometimes not valid when applied to practical electromagnetic engineering problems. It is therefore necessary to introduce powerful numerical techniques employing personal computers into the first introductory EM course. In view of the explosion in the undergraduate electronic and electrical engineering curriculum in recent years, the time_content limitation in adding the computer technique to the EM course must also be taken into consideration.

At the National Taiwan Institute of Technology, a course in introductory EM is required for undergraduate electronic engineering majors. This course is of one semester duration and carries a credit load of three hours. In this paper, we describe and illustrate a semi_interactive pedagogical program developed by the authors for PC_assisted electrostatics instruction that comprises almost one third of the introductory EM course. Starting from the most commonly_used integral equation in introductory EM, this program is designed by using the method of moment (Harrington, 1980), and can be used to analyze charge and field distribution, edge effects, and capacitance of both circular and rectangular capacitors. This program includes the use of both cartesian and cylindrical coordinates in computation. It also contains three commonly_used numerical techniques–Inverse matrix, Gauss elimination, and LU_decomposition (Gerald and Wheatley, 1984)–to provide the undergraduate students with an opportunity to practice and evaluate their time_efficiency in solving associated matrix equations. This educational software is designed for use in the classroom in conjunction with the lecture_discussions of the subject matter, as well as outside the classroom by students at their own leisure.

II. Method of Designing This Educational Program

Consider charged parallel_plate capacitors as shown in Fig. 1. The electric potential $V(\overline{r})$ at any field point of position vector $\overline{r}$ is produced by the total charge on the two conducting plates, and can be expressed as the following integral equation:

$$V(\overline{r}) = \frac{1}{4\pi\epsilon_0}\int_{S'} \frac{\rho(\overline{r}')\,ds'}{|\overline{r} - \overline{r}'|} \tag{1}$$

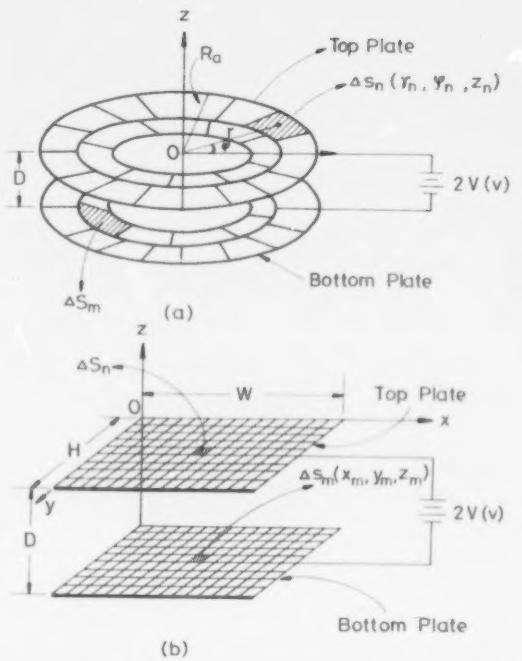

Fig. 1. Geometries and coordinates of charged parallel_plate capacitors: (a) circular plate, (b) rectangular plate.

where $\overline{r}'$ is the position vector of a source point that has a very small surface element ds' of charge density $\rho(\overline{r}')$, $|\overline{r} - \overline{r}'|$ is the distance from the source point to the field point, and S' is the total charged area of the capacitors, which may contain both positively and negatively charged plates. In eq.(1) the integration is carried only over the surface of the conducting plates since there is no charge distribution inside the volume of the conductors in the electrostatic condition, which is a conseqence of Gauss's law. The symbol ϵ_0 denotes the electric permitivity of the medium, which has the value of 8.85×10^{-12} farad/m for air. Eq (1) can be considered to be the integral solution of Poisson's differential equation ($\nabla^2 V = -\rho/\epsilon_0$) as found in an introductory electromagnetics textbook.

When each charged plate is divided into a number of small subarea S_m'(m=1, 2, ..., k), and these subareas are chosen to be sufficiently small, then the surface charge density ρ can be considered to be constant on each subarea. If ρ_m denotes the charge density on the m-th subarea S_m and the center position of S_m is $\overline{r}_m$, then the electric potential V_n at the point $\overline{r}_n$ can be approximated from eq (1) as

$$V_n = V(\vec{r}_n) \approx \frac{1}{4\pi\epsilon_0}\sum_{m=1}^{2k}\rho_m\int_{S_m'}\frac{ds'}{|\vec{r}-\vec{r}'|} \qquad (2)$$

Here, the integration over S′ in (1) is now replaced in (2) by a sum $\sum_{m=1}^{2k}$, and each term of the summation includes an integration over the corresponding subarea S_m'. If we choose to determine the 2k unknown charge densities ρ_m (m=1, 2, ..., 2k) by utilizing the 2k known values of the potential V_n (n=1, 2, ..., 2k) at the center of the 2k area elements, we obtain

$$V_{up} = \frac{1}{4\pi\epsilon_0}\sum_{m=1}^{2k}\rho_m\int_{S_m'}\frac{ds'}{|\vec{r}_n-\vec{r}'|} \qquad (n=1, 2, ..., k)$$

$$V_{dm} = \frac{1}{4\pi\epsilon_0}\sum_{m=1}^{2k}\rho_m\int_{S_m'}\frac{ds'}{|\vec{r}_n-\vec{r}'|} \qquad (n=k+1, ..., 2k) \qquad (3)$$

In (3), the constant potential value $V=V_{up}$ was used at each center of the k sections on the top equipotential plate, while another constant potential value $V=V_{dm}$ was used on the lower equipotential plate. For a potential difference 2V applied between the plates, the higher potential plate will be positively charged, whereas the lower potential plate will be negatively charged with the identical distributions of charge density. Hence it is only necessary to find the charge density distribution on one conducting plate by letting the potentials on the two plates to be $V_{dm}=-V_{up}=V$. The simultaneous equations in (3) can now be expressed as the following matrix equation:

$$\begin{vmatrix}[V_t]\\ [V_b]\end{vmatrix} = \begin{vmatrix}[\ell_{tt}] & [\ell_{tb}] & [\rho_t]\\ [\ell_{bt}] & [\ell_{bb}] & [\rho_b]\end{vmatrix} \qquad (4)$$

where the subscripts t and b denote "top plate" and "bottom plate", respectively, and the 1×k column vectors $[V_t]$, V_b, $[\rho_t]$ and $[\rho_b]$ represent the potential distribution and surface charge density distribution on the top and bottom plate, respectively, which can be expanded as $[V_t]=-[V_b]=[V, V, ..., V]^t$, and $[\rho_t]=-[\rho_b]=[\rho_1, \rho_2, \rho_k]^t$; here the superscript t denotes the transpose of the row vector. Each element ℓ_{mn} (m, n=1, 2, ..., k) of the four k×k submatrices $[\ell_{tt}]$, $[\ell_{bb}]$, $[\ell_{tb}]$, and $[\ell_{bt}]$ represents the potential at the center of S_m due to a uniform charge density of unit amplitude over the n-th subarea S_n which can be obtained from (3) as

$$\ell_{mn} = \int_{S_m'}\frac{ds'}{4\pi\epsilon_0|\vec{r}_n-\vec{r}'|} \qquad (5)$$

The submatrices $[\ell_{tt}]$ and $[\ell_{bb}]$ on the diagonal of (4) are single-plate submatrices, so $[\ell_{tt}]=[\ell_{bb}]$; the off-diagonal submatrices $[\ell_{tb}]$ and $[\ell_{bt}]$ are the plate-to-plate matrices, which must be equal by symmetry. Since both the potential and charge distribution on the top plate are minus that on the bottom plate, the matrix equation (4) of 2k dimensions can be simplified to the following k-dimensional matrix equation:

$$\{[\ell_{tt}]-[\ell_{tb}]\}[\ell_{tt}]=[V_t] \qquad (6)$$

For the circular charged capacitor in Fig. 1(a), the off-diagonal elements in the k×k submatrices $[\ell_{tb}]$ and $[\ell_{tt}]$ can be approximated in term of cylindrical coordinate as

$$(\ell_{tt})_{mn} = \frac{S_m}{4\pi\epsilon_0\sqrt{r_n^2+r_m^2-2r_nr_m\cos(\Theta_n-\Theta_m)}}$$

$$(\ell_{tb})_{mn} = \frac{S_m}{4\pi\epsilon_0\sqrt{r_n^2+r_m^2-2r_nr_m\cos(\Theta_n-\Theta_m)+D^2}} . \qquad (7)$$

But for the rectangular charged capacitor shown in Fig. 1(b), the corresponding off-diagonal elements must be approximated in cartesian coordinate as

$$(\ell_{tt})_{mn} = \frac{S_m}{4\pi\epsilon_0\sqrt{(x_n-x_m)^2+(y_n-y_m)^2}}$$

$$(\ell_{tb})_{mn} = \frac{S_m}{4\pi\epsilon_0\sqrt{(x_n-x_m)^2+(y_n-y_m)^2+D^2}} \qquad (8)$$

here the symbol $D=|z_n-z_m|$ in both (7) and (8) is the distance between the parallel conducting plates.

To overcome the singularity problem in (7) and (8) when m=n, the diagonal elements of $[\ell_{tt}]$ and $[\ell_{tb}]$ require special treatment. We can approximate each subarea S_n by an equivalent circular one of the same area and use values of the potential equal to that calculated at center of a circular area (Harrington, 1980). For a circular area of radius $a=\sqrt{S_n/\pi}$, the potential of a point at its center due to its own uniform charge distribution is given by

$$(\ell_{tt})_{nn} = \int_0^{2\pi}\int_0^{a} \frac{r'd\Theta'dr'}{4\pi\epsilon_0 r'} = \frac{0.282}{\epsilon_0}\sqrt{S_n}$$

$$(\ell_{tb})_{nn} = \int_0^{2\pi}\int_0^{a} \frac{r'd\Theta'dr'}{4\pi\epsilon_0\sqrt{r'^2+d^2}}$$

$$= \frac{0.282}{\epsilon_0 a}\sqrt{S_n}\,\{\sqrt{a^2+d^2}-d\} \qquad n=1, 2, \ldots, k \quad (9)$$

We can use (9) in (6) for the diagonal elements in the coefficient matrix. Notice that (9) is valid for the divided elements of both rectangular and circular parallel_plate capacitors provided an appropriate division of the charged plate is carried out. It is noted that the matrix equation (6) can also be used to analyze charged capacitors with a single conducting plate by simply deleting the submatrix $[\ell_{tb}]$ in (6) because D approaches infinity in this case.

To solve the matrix equation (6), which is of the type A X=B, three commonly_used numerical methods (Gerald, 1984; Harrington, 1980) can be used. In the inverse matrix method, the unknown column vector X is solved by computing the inverse matrix A^{-1} of the known matrix A and multiplying with the known matrix B to obtain $X=A^{-1}B$. In the Gauss elimination method, the elementary row transformation is performed to convert A to a upper triangular matrix A′ and to convert B to B′; then the unknown X is solved by back-substitution step from the derived A′ and B′. In the LU-decomposition method, the matrix A is transformed into the product of two matrices L and U, where L is a lower triangular matrix and U is an upper triangular matrix with 1's on its diagonal; the original matrix equation AX=LUX=B is then decomposited into two matrix equations LY=B and UX=Y, and the unknown X can be obtained from U and Y after solving Y byLY=B.

By using a two-dimensional array to store the matrix elements in (6) and two one-dimensional arrays to store the elements of $[\rho_t]$ and $[V_t]$, the surface charge density distribution $[\rho_t]$ can be solved by any one of the above mentioned numerical techniques. After the evaluation of charge distribution, the capacitance of the two plates connected together is then

$$C = \frac{\text{total charge}}{\text{potential difference}} = \frac{\sum_n \rho_n S_n}{2V} \qquad (10)$$

To enhance the student's depth of understanding, the degree of accuracy by using various size of the matrix in (6) should be mentioned. Apparently a tradeoff between the degree of accuracy and PC run_time is necessary.

III. Illustrative Examples and Discussions

Based on the process mentioned above, an educational electrostatics program for introductory electromagnetics has been established. Through a semi-interactive method, any one of the associated charged capacitors and any method of the three different numerical techniques for solving the matrix equations (6) can be selected for analysis by undergraduate students, thus providing the EM students a constructive practice in using the digital computer to solve engineering problems. In Figure 2, the software flowchart is depicted. The associated program in Fortran language is obtainable from the authors. We shall now present some examples to illustrate and discuss the teaching and learning aspects of the software.

Example 1.

Thin straight metallic strip: In this example, a thin straight conducting strip of length W=10.5 cm and width H=0.5 cm (see the top plate of Fig. 1(b) with D→∞) held at a constant potential of +1 volt is considered. The strip is divided into a number of segments of equal lengths and the charge density in each segment is assumed to be uniform. Choosing n=21 as the number of segments, the evaluated results of the associated matrix equation by the LU method for the 21 normalized unknown charge densities are illustrated in Table 1. The normalized charge distribution of this thin charged conducting strip is then plotted in Fig. 3, where the computed maximum charge density is 1.3204E-3 nc/cm^2. It is found that the charge distribution is symmetrical with respect to the middle segment, and there are only INT((n+1)/2) independent charge densities, where INT stands for "integer part of". As expected, the charge distribution edge effect is shown in Fig. 3. When the assigned equipotential value of the charged strip is doubled, the evaluated normalized charge distribution is found to be unchanged, but the calculated maximum charge density and hence the associated electric field around the strip edges is also doubled.

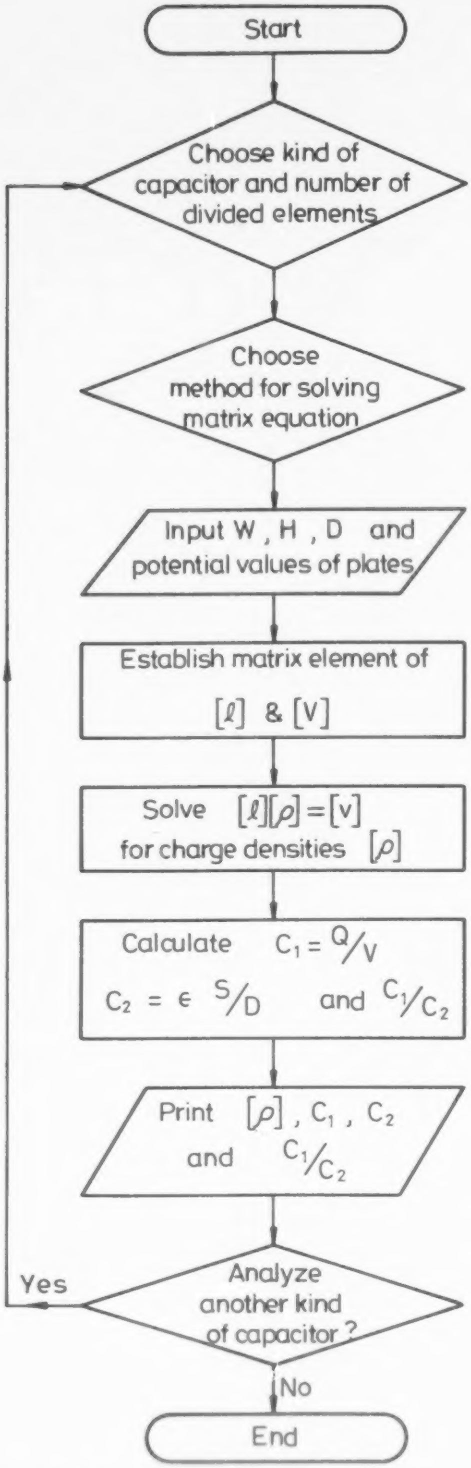
Start
Choose kind of capacitor and number of divided elements
Choose method for solving matrix equation
Input W , H , D and potential values of plates
Establish matrix element of
[ℓ] & [V]
Solve [ℓ][ρ]=[V]
for charge densities [ρ]
Calculate C₁ = Q/V
C₂ = ε S/D and C₁/C₂
Print [ρ] , C₁ , C₂
and C₁/C₂
Analyze another kind of capacitor ?
Yes
No
End

Fig. 2. Flowchart of the educational program.

Table 1. Normalized Charge Density (Cn) along a Thin Straight Conducting Strip of Length 10.5 cm, Width 0.5 cm, and Held at +1 Volt Potential. Calculated Maximum Charge Density is 1.3204E-3 nc/cm^2 and x (cm) is the Distance from the Left End of the Strip

x	Cn	x	Cn	x	Cn
0.25	1.000	3.75	0.6280	4.25	0.6336
0.75	0.7470	4.25	0.6243	7.75	0.6418
1.25	0.6984	4.75	0.6222	8.25	0.6534
1.75	0.6707	5.25	0.6215	8.75	0.6707
2.25	0.6534	5.75	0.6222	9.25	0.6984
2.75	0.6418	6.25	0.6243	9.75	0.7470
3.25	0.6336	6.75	0.6280	10.25	1.000

Example 2.

Thin square conductor: In this example, a thin, square conducting plate of side W=H=2 cm (see the top plate of Fig. 1(b) with $D \rightarrow \infty$) held at a constant potential of +2 volt is considered. The conducting plate is divided into a number of squares of equal area and the charge density in each sub-area is assumed to be uniform. If each side is divided into n equal parts, then there are n×n squares. Choosing n=8 cm, so that there are 64 charge densities to be determined, the solution for the corresponding matrix equation by the LU method is illustrated in Table 2. It can be found from Table 2 that the charge distribution is now symmetrical with respect to the central divided element, and there are only k(k+1)/2 independent charge densities where k is equal to INT((n+1)). Besides the edge effect at the outter part of the charged plate, it is noted that the evaluated charge distribution and hence the associated electric field intensity is strongest at the four corner points, which agrees with the theoretical predictions concerning electrostatic charges and fields [1993, Cheng]. Shown in Fig. 4 is the three-dimensional charge distribution for n=20 and W=H=2 cm, which has been plotted by two junior students employing the present program.

Example 3.

Two parallel, square conductors: This examples extends example 2 by considering two parallel, square conductors, hence illustrating the arrangement of a parallel-plate capacitor. The size of each plate is assumed to be W=H=2 cm, and the separation between the plates is assumed to be

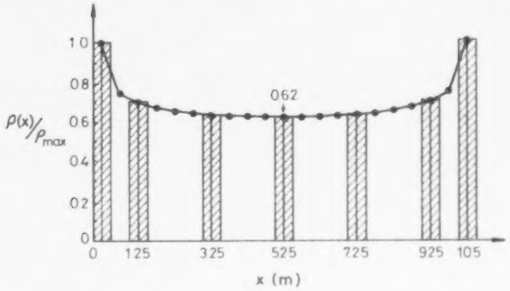

Fig. 3. Charge distribution along a thin, straight, conducting strip of length W=10.5 cm, and width H=0.5 cm held at a potential of 1 volt. (1 ×21 mesh division).

Table 2. Normalized Charge Density Distribution of a Thin Square Plate with W=H=2 cm Held at a Potential of +2 Volts. The Mesh Division is N×N=8×8 and the Calculated Maximum Charge Density is 4.3071E-13 (c/cm²)

1.0000	.6667	.6156	.5952	.5952	.6156	.6667	1.000
.6667	.3464	.3090	.2945	.2945	.3090	.3464	.6667
.6156	.3090	.2706	.2559	.2559	.2706	.3060	.6156
.5952	.2945	.2559	.2411	.2411	.2559	.2945	.5952
.5952	.2945	.2559	.2411	.2559	.2945	.5952	
.6156	.3090	.2706	.2559	.2559	.2706	.3090	.6156
.6667	.3464	.3090	.2945	.2945	.3090	.3464	.6667
1.0000	.6667	.6156	.5952	.5952	.6156	.6667	1.0000

D=W. (see Fig. 1(b)). As indicated before, by letting the potentials on the two plates to be equal in magnitude and opposite in sign, it suffices to find the charge density distribution on one conductor. Here, the positively charged plate held at +1 volt potential is considered.

Choosing first n=8 as in the case of the single conductor, the solution for the normalized 8 × 8 unknown charge densities is illustrated in Table 3 (a), where the maximum charge density is 5.9165E-13 c/cm². Note that the charge distribution in Table 3(a) is different from that in Table 2, which is due to the presence of the negatively charged plate. Also reproduced in Table 3 (a) are the total charge (Q) on the one charged plate, the capacitance (C_1=Q/2) of the parallel–plate capacitor, and its ratio to the capacitance ($C_2=\epsilon_0 W^2/D$) of the same arrangement computed by ignoring fringing of the field.

The user is then given the opportunity to input sets of values for the parameters W, H, D, and carry out the analysis. Two important cases are as follows:

(a) D/W=0.001, n=8. This is the case where the spacing between the plates is very small when compared with the dimensions of the plates. Hence the fringing of the electric field can be ignored, the computed charge distribution is nearly uniform, and C_1/C_2 is almost equal to unity. The calculated result is reproduced in Table 3(b).

(b) D/W=1000, n=8. This is the case where the spacing between the plates is very large as compared with the dimensions of the plates. The edge effect and sharp point effect of the surface charge distribution are most apparent in this case as seen from the calculated output reproduced in Table 3(c). Note that both the charge distribution and the capacitance C_1=Q/2 in Table 3(c) are almost identical to those in Table 2.

Example 4.

Thin circular conductor: In this example, a thin circular conducting plate of radius Ra=1 cm held at a constant potential V=+2 volt is considered (see the top plate in Fig. 1(a) with D→∞). This circular plate is first divided into a selected number, say n+1, of concentric annular regions of identical radial thickness Ra/n; then the m-th annular region between the radius r_m=m (R/n) and r_{m-1}=(m+1)R/n, where m is an integer, is again divided into n_m number of segments of identical area where n_m=INT($2\pi r_m$+0.5). The circular region inside the minimum radius r_1=(R/n) is chosen to be one of the divided segments. The charge density inside each divided segment is assumed to be uniform, and the center point of the i-th divided segment is denoted by a set of cylindrical coordinates (r_i, φ_i, z_i). Choosing n=6, there are 152 unknown charge densities to be evaluated; however since the solution of the corresponding matrix equation exhibits circular symmetry, there are only (n+l) independently calculated charge densities. In Table 4, the evaluated normalized charge density (Cn) is reproduced with the maximum density 4.1375-13 c/cm². It exhibits a radial edge effect of charge distribution.

Example 5.

Two parallel, circular-shaped conductor: This example extends example 4 by considering two parallel, circular-shaped conductors, illustrating

Table 3. Normalized Charge Density Distribution and Capacitance of a Square Parallel-Plate Charged Capacitor of W=H=2 cm Held at a Potential Difference of 2 Volts. D is the Separation of the Square Plated, C1=Q/2, C2= $\epsilon_0 S/D$, and N×N=8×8 is the Division Number

(a) D/W=1, C1=Q/2V=5.675E-13 (F)
Max charge density=5.916548E-13 (c/cm^2), C1/C2=3.2096

1.0000	.6792	.6342	.6169	.6169	.6342	.6795	1.0000
.6792	.3661	.3326	.3201	.3201	.3326	.3661	.6792
.6342	.3326	.2981	.2854	.2854	.2981	.3326	.6342
.6169	.3201	.2854	.2725	.2725	.2854	.3201	.6169
6169	.3201	.2854	.2725	.2725	.2854	.3201	.6169
.6342	.3326	.2981	.2854	.2854	.2981	.3326	.6342
.6792	.3661	.3326	.3201	.3201	.3326	.3661	.6792
1.0000	.6792	.6342	.6169	.6169	.6342	.6792	1.000

(b) D/W=0.001, C1=1.775E-10 (F)
Max charge density=8.8895E-11 (c/cm^2), C1/C2=1.0036

1.0000	.9990	.9989	.9988	.9988	.9989	.9990	1.0000
.9990	.9979	.9976	.9976	.9976	.9976	.9979	.9990
.9989	.9976	.9974	.9973	.9973	.9974	.9976	.9989
.9988	.9976	.9973	.9972	.9972	.9973	.9976	.9988
.9988	.9976	.9973	.9972	.9972	.9973	.9976	.9988
.9989	.9976	.9974	.9973	.9973	.9974	.9976	.9989
.9990	.9979	.9976	.9976	.9976	.9976	.9979	.9990
1.0000	.9990	.9989	.9980	.9988	.9989	.9990	1.0000

(c) D/W=1000, C1=3.949E-13 (F)
Max charge density=4.3086E-13 (c/cm^2), C1/C2=2232

1.0000	.6667	.6156	.5952	.5952	.6156	.6667	1.0000
.6667	.3464	.3090	.2945	.2945	.3090	.3464	.6667
.6156	.3090	.2706	.2559	.2559	.2706	.3090	.6156
.5952	.2945	.2559	.2411	.2411	.2559	.2945	.5952
.5952	.2945	.2559	.2411	.2411	.2559	.2945	.5952
.6156	.3090	.2706	.2559	.2559	.2706	.3090	.6156
.6667	.3464	.3090	.2945	.2945	.3090	.3464	.6667
1.0000	.6667	.6156	.5952	.5952	.6156	.6667	1.0000

Table 4. Normalized Charge Density (Cn) Distribution of a Thin Charged Circular Plate of Radius 1 cm Held at +2 Colt Potential. R/Ra is the Relative Radial Distance from Center of one Plate

Maximum charge density is 4.1375E-13 (c/cm^2)

R/Ra	Cn
0.0000	0.2624
0.2308	0.2871
0.3846	0.2969
0.5385	0.3225
0.6923	0.3981
0.8462	0.4520
1.0000	1.0000

Table 5. Normalized Charge Density Distribution and Capacitance of a Circular Parallel_Plate Capacitor of Radius Ra=1 cm Held at a Potential Difference of 2 Volts. D/Ra is the Relative Separation Between the Plates

R/Ra	(a) D/Ra=1 C1/C2=2.2639 C1=6.288E-13F	(b) D/Ra=1000 C1/C2=1250 C1=3.474E-13F	(c) D/Ra=0.001 C1/C2=1.002 C1=2.785E-10F
0.0000	0.3471	0.2624	0.9973
0.2308	0.3751	0.2871	0.9984
0.3846	0.3781	0.2969	0.9984
0.5385	0.3952	0.3225	0.9984
0.6923	0.4278	0.3681	0.9985
0.8462	0.4934	0.4520	0.9988
1.0000	1.0000	1.0000	1.0000

the arrangement of a circular parallel-plate capacitor. Here, the radius of each charged plate (see Fig. 1(a)) is assumed to be Ra=1 cm, and the separation between the plates is D. By allowing the potentials on the two plates to be equal in magnitude and opposite in sign, only the positive charge density on the upper circular plate is needed when calculating the charge densities.

Choosing n=6 and D=Ra=1 cm, the evaluated results are reproduced in Table 5(a). The presence of the negative charged plate causes a different charge distrubution from that of Table 4, but the edge effect of charge distribution is still apparent.

Again, the parameters of the charged capacitor can be changed by students to investigate various possible results. Two interesting cases are as follows:

(a) D/Ra=0.001, n=6. In this case the spacing between the circular plates is very small as compared to the radius of the plate. The evaluated charge density distribution is nearly uniform, and the ratio C_1/C_2 is almost equal to unity, as shown in Table 5(c). The fringing of the electric field is thus negligible when Ra>>D.

(b) D/Ra=1000, n=6. In this case the spacing between the circular plates is very large as compared with the radius of the plates. The evaluated charge densities exhibit a strong edge effect as reproduced in Table 5(b). Note that the results in this table are almost identical with those in Table 4, and hence a single positively charged plate can be considered as a

Table 6. Comparision of Required Time (in Seconds) for Different Numerical Methods in Solving the Charge Densities of a Circular Parallel_Plate Capacitor of Ra=D=2 cm on a 90486 DX2-66 PC with 16 M RAM

Number of divided unknowns	Inverse matrix	Gauss's elimination	LU decomposition
111	18 s	9.4 s	7.0 s
252	201 s	141 s	69 s
312	379 s	188 s	128 s
705	4311 s	2128 s	1453 s
906	9142 s	3612 s	insufficient memory

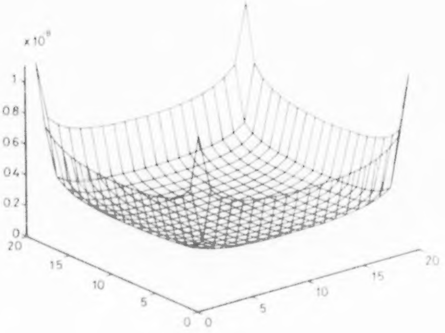

Fig. 4. Charge density distribution for the positive charged plate of a square parallel_plate capacitor of W=H=2 cm held at potential difference of 2 volts. (20×20 mesh).

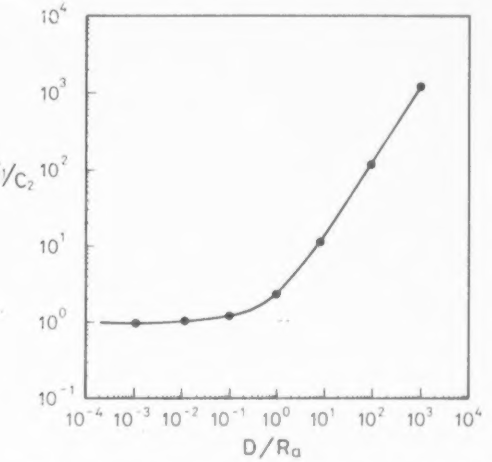

Fig. 6. Relative capacitance C_1/C_2 versus relative plate distance D/Ra of a circular parallel_plate of radius Ra=1 cm held at a potential difference of 2 volts. (division number NS=133)

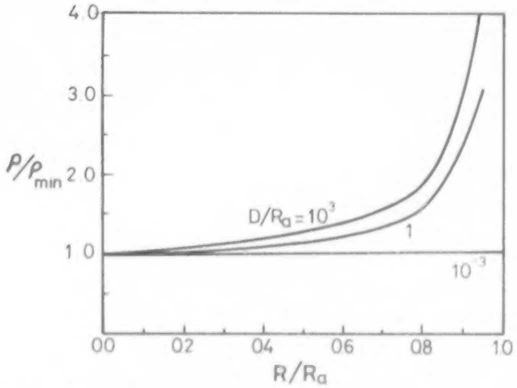

Fig. 5. Relative charge density versus relative radial distance from the center origin of a circular parallel_plate capacitor with the relative distance between two charged plate as a parameter (radius Ra=1 cm, potential difference=2 volts).

capacitor with its negatively charged plate placed at infinity.

Shown in Fig. 5 is the relative radial charge density distribution (ρ/ρ_{min}) versus relative radial distance (R/Ra) from the plate center with the relative plate distance D/Ra as a parameter, which provides a comparision of edge effect due to relative plate separation. The variation of the capacitance ratio C_1/C_2 with the relative separation D/Ra is plotted in Fig. 6. Many students are surprised by the result of Fig. 6 because they have the misconception that the capacitance formula $C_2=\epsilon_0 S/D$, and hence C_1/C_2, is independent of the distance between the charged plates.

Example 6.

Time_efficiency comparision of different numerical methods in solving for a given parallel-plate capacitor: When the number of segments in analyzing the charge densities of a charged capacitor is given on a given digital computer, the required time for solving the charge densities is different with different numerical techniques. In the present pedagogical program, three different numerical methods have been included for solving matrix equations, and this can provide students an opportunity to compare the methods' time_efficiency in solving engineering problems. Shown in Table 6 is the result for the different division number of a given circular parallel_plate capacitor carried out on a 80486 DX2-66 personal computer (with 16 M RAM). Note that the Gauss_elimination method is more powerful than the inverse_matrix method, but the LU_decomposition is the most time efficient method. The difference in spent time rises with an increase in the divided segments. One disadvantage of the LU_method is the requirement for more memory.

IV. Conclusion

The comprehensive, semi_interactive program described in this paper is a result of an effort by the authors to enhance the teaching and learning processes in the introductory electromagnetics course at the National Taiwan Institute of Technology. The use of this program in the classroom, integrated in conjunction with the lecture_ discussions of the subject matter, enables the instructor to illustrate in a convenient manner some important concepts in electrostatics. This software also provides an opportunity to allow the students to explore individually at their own pace and leisure, and hence enhances their learning of the subject matter.

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Refferences

Broschat, S. L., (1993) Interactive software for undergraduate electromagnetics, *IEEE Trans. Educ.*, **36**, 123-126.

Coren, R. L. (1993). Computational techniques in the first course on electromagnetism, *IEEE Trans. Educ.*, **36**, 230-232.

David, A. de Wolf. (1994). Error analysis when solvng Laplaces's equation numerically by iteration. *IEEE Trans. Educ.*, **37**, 84-86.

David K. Cheng. (1993). Fundamentals of engineering electromagnetics, 100-109.

Gerald, C. F. & Wheatley, P. O. (1984). Applied numerical analysis, third edition. chapter 2, 91-99.

Hoburg, J. F. (1993). Can computers really help students understand electromagnetics?. *IEEE Trans. Educ.*, **36**, 119-122.

Hoburg, J. F. (1987). Personal computer_based educational tools for visualization of applied electromagnetics and magnetquasistatic problems. J. Electrostatics, Vol. 19, 165-179.

Harrington, R. F. (1980). Field computation by moment method, McGraw Hills Inc. second edition.

Iskander, M. F. (1991). NSF/IEEE center for computer applications in electromagnetics education (CAEME), software book, vol. 1, Univ. of Utah, Salt Lake city.

Iskander, M. F. etc (1988) A new course on computational methods in electromagnetics, *IEEE Trans. Educ.*, **31**, 2, 101-114.

Rao, N. N., (1990). PC-Assisted Instruction of Introductory Electromagnetics, *IEEE Trans, Educ.*, **33**, 51-59.

在基礎電磁學課程中靜電學的電腦輔助教學

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摘　　要

爲了提昇大學生對電磁學的學習興趣及效果，本文提出一教學程式。此教學軟體涉及不同的荷電電容器，在計算上使用直角座標及圓柱座標，並且包含三種不同的解矩陣方程式的方法。程式中之某些參數可由學生加以改變，俾用以探究傳統課堂難以處理之靜電學問題。

本文中描述此一教學軟體之設計方法並舉出一些例題加以說明，一些觀念及學生之反應也包含於此等說明例中。又荷電圓形平行板電容器在執行分析時用不同數值方法之時間效率的比較亦於例題中加以說明。

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Using Fuzzy Sets in Developing Mathematical Learning -Progress Indicator[†]

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ABSTRACT

Nowadays, the demand for more valid and reliable educational indicators has grown significantly as to monitor qualitative changes in the educational system over time. As recommended by the Committee on Indicators of Precollege Science and Mathematics Education, the indicator of student learning progress should be given the highest priority in developing of any educational indicator system. In fact, our society and educational policymakers concern that the indicator of student learning progress should be based on achievement test scores. With this in view, the measuring method toward it is especially important. On the basis of fuzzy set theory and its algorithms, we, therefore, attempt to develop a structural model for establishing the indicator of learning progress in mathematics and propose an algorithm with it.

Moreover, we provided an example, in a practical setting, to demonstrate how to use the algorithm. The methodology we employed in the example was Delphi's technique. This ended up with a questionnaire consisting of 40 multiple choices about the concept of triangle. The subjects involved were students from four randomly chosen high schools in the Taipei area. This gave us a total of 359 subjects, from 7th-grade to 10th-grade. Besides, we also demonstrate how to interpret and implicate those information provided by our example.

Thus, the purpose of this study is to try to design a reliable and valid tool to help with the development of the learning progress indicator; and provide information of how to interpret and implicate the indicator as a reference to improve the quality of mathematics education in Taiwan.

Key words: fuzzy set theory, membership functions, linguistic modelling, indicators, learning progress

I. Introduction

The recognition that educational systems are changing rapidly is widespread in Taiwan. Most of the changes are spurred by and give rise to human's demand of different approaches of being well-educated. During the inspiring period of educational reform, we should recognize that something is needed in order to provide clues to monitor or assess the existing or proposed educational reform programs. According to Murnane and Raizen (1988), they declared that the notion of indicator systems was fundamental to the concept of monitoring and statistics were the building blocks of indicator systems. Most often, the statistics that were derived from a test, a survey, or a collection of information on some important quantitative or qualitative aspects of an educational system are designed to be useful in describing the aspects that the statistics pointed at.

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Once a statistic has been established for a given indicator, there are several possible approaches to interpret it. First, the statistic of an indicator may be compared with some absolute or ideal standards of a particular construct to which the indicator refers. This kind of comparison shows whether a particular component of an educational system is good enough or not. A second interpretation involves comparison of a given indicator with its value at some prior time. This can reveal whether a particular component of an educational system has changed over time. Third, indicators can also be presented as a basis for the comparison of instructional programs, demographic groups, regions, and so on. As a result, they provide information about any differences that exist between or among the constructs.

Of all educational indicators, Shavelson, McDonnell, Oakes, and Carey (1987) claimed that achievement indicators, which aggregate statistics based on achievement test scores, are the most center-piece of any educational indicator system and should be given the highest priority in developing of any educational indicator system. In fact, achievement indicators represent the essence of schooling that can show whether students have learned what they have been taught. And achievement outcomes are generally seen as the final "proof" of an education system's quality (Shavelson, McDonnell, and Oakes, 1989).

When students are assessed, the information collected must be aggregated to draw meaning from what is measured. It is widespread agreement that the process of aggregating information is very important and should be addressed. One of the problems associated with assigning a single score to a student is how to combine her/his different test scores sensibly. In the traditional approach, the most relevant way to combine different results is by z-score. The reason of using the z-score is to obtain a more representative estimate of a student's total relative position. Moreover, it is also possible to ascribe varying degrees of importance to different achievement tests by weighting the z-scores for the given tests.

Since the introduction of fuzzy set theory in 1965 (Zadeh, 1965), a number of introductory books have appeared, such as: Fuzzy Set Theory and its Applications (Zimmermann, 1991); Introduction to Fuzzy Arithmetic (Kaufmann, 1991), etc. Moreover, applications of this theory can also be found in many fields, including expert systems (Kastner & Hong, 1984), decision making (Kickert, 1978), operations research (Chanas, 1982), pattern recognition (Bezdek, 1981), behavioral social sciences (Smithson, 1987), and educational assessment (Law, in press), etc.

With the algorithms provided by Law as to show how to assign grades for students, several questions naturally arise: "Is it appropriate to use the fuzzy set theory in establishing an indicator for students' learning progress?" , "How to apply the fuzzy set theory to develop a structure model for an indicator of learning progress?" , "What are the advantages of using a 'fuzzy' learning progress indicator?"

Thus, this study is an attempt to try to design a reliable and valid method of development a learning progress indicator, and provide information on how to interpret and implicate the indicator as a reference to improve the quality of mathematics education in Taiwan.

II. Is it Appropriate to Use Fuzzy Sets in Establishing an Indicator of Learning Progress?

There are three main reasons for the use of fuzzy set theory in establishing an indicator of learning progress:

a. It is well-known that test scores for individuals will fluctuate a little from one occasion to the next. It implies that the observed scores to characterize students are not very precise. Moreover, it is believed that an observed score is made up of a true score and an error score. Consequently, the observed scores of students are vague data.

b. Likewise, the scores of different questions in an achievement test are also vague data. Hence, it is sound to use the fuzzy set theory to aggregate scores of different questions in order to produce an overall assessment score for a test. Moreover, a systematic fuzzy approach (Law, in press) has been devised to classify students' achievement levels relative to absolute or ideal standards. Therefore, we have a valid method of aggregating scores in fuzzy environment.

c. Learning progress can be easily understood in terms of achievement levels. In fact, the most common description for students' achievement levels is the use of grade levels, such as 7th-grade, 8th-grade, or 9th-grade, etc. Thus, we propose to use grade levels to summarize students' achievement levels or students' learning progress. Obviously, grade level is a linguistic variable that we employ to communicate with people. Thus, it is adequate to use the fuzzy set theory in establishing an indicator of learning progress.

III. Methods

1. Subjects

The subjects involved in this research were students from four randomly chosen high schools in the Taipei area, two from downtown and the others from suburbs. Particularly, two junior high schools and two senior high schools were included. As a result, there were 75 7th-grade, 75 8th-grade, 81 9th-grade, and 128 10th-grade students in the study sample. This gave us a total of 359 subjects.

2. Limitations of the Study

Since the aim of our research is to try to demonstrate how to use fuzzy set theory in developing a learning progress indicator, we would like to choose only one of the most important mathematical concepts in the high school mathematics curriculum. Moreover, we would rather study the conceptual understanding than the skills and problem-solving abilities of students.

After thorough consideration, the concept of triangles was selected to be studied in our research. The reason we chose it was that this concept was involved only in the 7th-grade and 9th-grade, and not in the 8th-grade and 10th-grade school mathematics curriculums. Thus, it would help us easily to see the progress of learning since our samples included 7th-grade to 10th-grade students. In other words, we might expect that the average scores for the 7th-grade and 8th-grade would close together, as would be those for the 9th-grade and 10th-grade.

Another limitation in our study was that we could not take a survey of all 7th-grade to 10th-grade students in Taiwan. Actually, only 359 students were involved. Of the three possible approaches to interpreting the indicator mentioned above, we prefer to only discuss the first approach since the other two were quite straightforward if information is sufficient.

3. Achievement Test

Since we had selected the triangle concept as an example to demonstrate in our study, we invited more than thirty educators to review its concept-mapping consisting of 10 subconcepts. For each subconcept, we designed 4 multiple-choice items and the wording of each question was very carefully scrutinized. A pilot examination was also held in order to check whether the distractors could perplex the unknowledgeable examinee from guessing the correct answer.

4. Fuzzy Numbers in the Learning Progress Indicator

Suppose that the possible observed scores of a subconcept are 0, 1, ..., n. According to Law's study, for an observed score i, the true score distribution function $f_i(x)$ is shown as follows, where x represents the true score of the observed score i.

$$f_0(x) = \begin{cases} 1 - nx & 0 \le x \le \frac{1}{n} \\ 0 & \frac{1}{n} < x \le 1 \end{cases}$$

$$f_n(x) = \begin{cases} 0 & 0 \le x \le \frac{n-1}{n} \\ nx - (n-1) & \frac{n-1}{n} < x \le 1 \end{cases}$$

$$f_i(x) = \begin{cases} 0 & 0 \le x \le \frac{i-1}{n} \\ nx - (i-1) & \frac{i-1}{n} < x \le \frac{i}{n} \\ (i+1) - nx & \frac{i}{n} < x \le \frac{i+1}{n} \\ 0 & \frac{i+1}{n} < x \le 1 \end{cases}$$

for i=1, 2, ..., n−1

From above, it should be noticed that

$\Sigma_{i=0}^{n} f_i(x)=1$ for all x in [0, 1]. Also, we can see that the true score distribution function $f_i(x)$ is continuous. Moreover, if the true score of a student is less than or equal to $\frac{i-1}{n}$ (greater than or equal to $\frac{i+1}{n}$), then her/his observed score should not be i. Furthermore, we can see that if the true score of a student is closer to i, then her/his observed score is more likely to be i. All these properties fit real-life situations.

For any observed score i of the subconcept, we desire to use the expectation value $\dfrac{\int_0^1 x f_i(x)\,dx}{\int_0^1 f_i(x)\,dx}$ as being its corresponding true score x_i, i=0, 1, ..., n. In fact, the corresponding true score x_i of an observed score i is shown as follows:

$$x_i=\begin{cases}\dfrac{1}{3n} & i=0\\ \dfrac{i}{n} & 0<i<n\\ 1-\dfrac{1}{3n} & i=n\end{cases}$$

It is rational to use the expectation values because, for example, a student getting 0 point on a subconcept does not mean that he/she knows nothing about that concept.

Since our subjects ranged from 7th-grade to 10th-grade, it was better to use six grade levels (6th-grade to 11th-grade) as students' learning progress. We, thus, assign the linguistic values G_6, G_7, G_8, G_9, G_{10} and G_{11} to these grade levels respectively. In addition, we need to transfer the linguistic values G_6, G_7, G_8, G_9, G_{10} and G_{11} into corresponding reasonable normal fuzzy numbers $\tilde{G}_6$, $\tilde{G}_7$, $\tilde{G}_8$, $\tilde{G}_9$, $\tilde{G}_{10}$ and $\tilde{G}_{11}$ with triangular membership functions $\mu_{\tilde{G}_6}(x)$, $\mu_{\tilde{G}_7}(x)$, $\mu_{\tilde{G}_8}(x)$, $\mu_{\tilde{G}_9}(x)$, $\mu_{\tilde{G}_{10}}(x)$ and $\mu_{\tilde{G}_{11}}(x)$. In order to mirror the true situation, the membership functions should satisfy the following criteria:

a. Let $\bar{G}_6=\{x\in[0,1] \mid \mu_{\tilde{G}_6}(x)\geq 0.5\}$ be the 0.5-level set of the fuzzy set $\tilde{G}_6$. Therefore, if a student's true score of a subconcept belongs to $\bar{G}_6$, then it suggests that her/his conceptual understanding of the subconcept should be in the 6th-grade level, etc.

b. The membership functions $\mu_{\tilde{G}_6}(x)$ and $\mu_{\tilde{G}_7}(x)$ should have an intersection point at which we can appoint students' grade levels effectively, etc.

c. For x in [0, 1], $\mu_{\tilde{G}_6}(x)+\mu_{\tilde{G}_7}(x)+\mu_{\tilde{G}_8}(x)+\mu_{\tilde{G}_9}(x)+\mu_{\tilde{G}_{10}}(x)+\mu_{\tilde{G}_{11}}(x)=1$. It shows that the sum of degrees of membership of all fuzzy sets at the point x should be 1. Since the grade level to be appointed corresponds to the degree of membership of the fuzzy sets, 'the degree of a true score x belonging to the 6th-grade' should be equal to '1 - the degree of x that does not belong to the 6th-grade.'

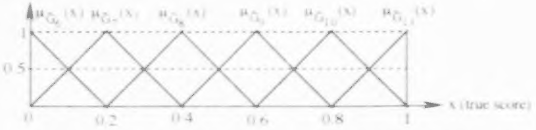

Fig. 1. The triangular membership functions.

Therefore, the membership functions are as shown in Figure 1 and the Appendix.

5. Algorithm Proposed to Aggregate scores of Different Subconcepts in an Achievement Test

Suppose that there are M subconcepts X_j in an achievement test, j=1, 2, ..., M. It may happen that certain subconcepts are more significant to distinct students' grade levels, for example the levels of difficulty of subconcepts. Hence, we can assign weightings no matter whether the subconcepts have different difficulty. Consequently, we let w_j to be the weight of the subconcepts X_j, j=1, 2, ..., M. In order to find the final grade levels of students, we intend to employ the centroid method to defuzzify students' aggregative scores. Therefore, we need to find the expectation values of the normal fuzzy numbers $\tilde{G}_6$, $\tilde{G}_7$, $\tilde{G}_8$, $\tilde{G}_9$, $\tilde{G}_{10}$ and $\tilde{G}_{11}$. It is quite natural to define the expectation of a fuzzy number $\tilde{G}_6$ in R^n as:

$$E(\tilde{G}_6)=\frac{\int_{R^n} x\mu_{\tilde{G}_6}(x)\,f(x)\,dx}{\int_{R^n} \mu_{\tilde{G}_6}(x)\,f(x)\,dx},$$

where f(x) is the distribution function of x in $\tilde{G}_6$.

In fact, $f(x)=\Sigma_{i=0}^{n} f_i(x)=1$ for all x in [0, 1], so we have $E(\tilde{G}_6)=0.0667$, $E(\tilde{G}_7)=0.2$, $E(\tilde{G}_8)=0.4$, $E(\tilde{G}_9)=0.6$, $E(\tilde{G}_{10})=0.8$, and $E(\tilde{G}_{11})=0.9333$.

Now, we try to present how to aggregate scores of different subconcepts in an achievement test. Let $s_1, s_2, \ldots, s_m$ be the raw scores of a student in M subconcepts, and let $s_1, s_2, \ldots, s_M$ be their corresponding true scores . Then, we can form a fuzzy assessment matrix A as:

$$A = \begin{array}{c|cccccc|} & \tilde{G}_6 & \tilde{G}_7 & \tilde{G}_8 & \tilde{G}_9 & \tilde{G}_{10} & \tilde{G}_{11} \\ X_1 & \mu_{\tilde{G}_6}(s_1) & \mu_{\tilde{G}_7}(s_1) & \mu_{\tilde{G}_8}(s_1) & \mu_{\tilde{G}_9}(s_1) & \mu_{\tilde{G}_{10}}(s_1) & \mu_{\tilde{G}_{11}}(s_1) \\ X_2 & \mu_{\tilde{G}_6}(s_2) & \mu_{\tilde{G}_7}(s_2) & \mu_{\tilde{G}_8}(s_2) & \mu_{\tilde{G}_9}(s_2) & \mu_{\tilde{G}_{10}}(s_2) & \mu_{\tilde{G}_{11}}(s_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_M & \mu_{\tilde{G}_6}(s_M) & \mu_{\tilde{G}_7}(s_M) & \mu_{\tilde{G}_8}(s_M) & \mu_{\tilde{G}_9}(s_M) & \mu_{\tilde{G}_{10}}(s_M) & \mu_{\tilde{G}_{11}}(s_M) \end{array}$$

For subconcept X_j, the fuzzy assessment matrix A indicates the degrees of membership of the student's corresponding true score s_j in each grade level. The student's aggregative score will be defuzzified by employing the centroid method as follows.

Let T

$=(T_1, T_2, \ldots, T_M)'$

$= A \times (E(\tilde{G}_6), E(\tilde{G}_7), E(\tilde{G}_8), E(\tilde{G}_9), E(\tilde{G}_{10}), E(\tilde{G}_{11}))'$

Then, the student's aggregative score w can be calculated by the formula $w=\Sigma_{j=1}^{M} w_j T_j$, where $w_1, w_2, \ldots, w_M$ are the weightings of the subconcepts. The aggregative score w can be employed to categorize the student's grade level according to which 0.5-level set it belongs in.

6. An example

We have 10 subconcepts in our study and the weight of the subconcepts (difficulty levels) is $(w_j)_{j=1}^{10}=(1, 1, 1, 3, 1, 3, 3, 2, 2, 3)$, where 1 stands for easy and 3 for difficult. If the raw scores of a student, according to the order of the subconcepts, are 4, 3, 4, 1, 4, 2, 3, 4, 2, 3, then her/his corresponding true scores should be 0.9167, 0.75, 0.9167, 0.25, 0.9167, 0.5, 0.75, 0.9167, 0.5, and 0.75. Therefore, the fuzzy assessment matrix of the student is:

$$A = \begin{array}{c|cccccc|} & \tilde{G}_6 & \tilde{G}_7 & \tilde{G}_8 & \tilde{G}_9 & \tilde{G}_{10} & \tilde{G}_{11} \\ X_1 & 0 & 0 & 0 & 0 & 0.1465 & 0.5835 \\ X_2 & 0 & 0 & 0 & 0.25 & 0.75 & 0 \\ X_3 & 0 & 0 & 0 & 0 & 0.4165 & 0.5836 \\ X_4 & 0 & 0.75 & 0.25 & 0 & 0 & 0 \\ X_5 & 0 & 0 & 0 & 0 & 0.4156 & 0.5835 \\ X_6 & 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ X_7 & 0 & 0 & 0 & 0.25 & 0.75 & 0 \\ X_8 & 0 & 0 & 0 & 0 & 0.4156 & 0.5835 \\ X_9 & 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ X_{10} & 0 & 0 & 0 & 0.25 & 0.75 & 0 \end{array}$$

Thus, we have:

$T=(0.8778, 0.75, 0.8778, 0.25, 0.8778, 0.5, 0.75, 0.8778, 0.5, 0.75)'$
$w=\Sigma_{j=1}^{10} w_j T_j=0.64445$

Since $\mu_{\tilde{G}_9}(0.64445)=0.77775$ and $\mu_{\tilde{G}_{10}}(0.64445)=0.22225$, it shows that $0.64445 \in \tilde{G}_9$. In other words, it suggests that this student's grade level should be 9th-grade. In fact, this student is a 10th-grade student. It means that the learning progress of this student is not good enough to be a 10th-grade student. More discussions will be found in section IV.

IV. Results and Discussions

Now, we attempt to show how to interpret and implicate the 'fuzzy' indicator as a reference for improving the quality of our mathematics education. With the stated fuzzy set theory algorithm, we can derive some statistics about students' achievement test scores and propose to analyze them in three different ways: (1) as a learning progress indicator of a group with a known grade level; (2) as a learning progress indicator of a group with an unknown grade level; and (3) as a learning progress indicator of a student.

1. Learning Progress Indicator of a Group with a Known Grade Level

First, we would like to report about the average of students' aggregate scores $\overline{w}$ in each grade level. These statistics can be used as learning progress indicators for the corresponding grade levels.

From Table 1, we can see that the learning progress indicators for each grade level are 0.3762, 0.3665, 0.6025, and 0.6985 respectively. How to apply and interpret these 'fuzzy' indicators? In other words, do some ideal standards (absolute reference points) exist for the learning progress indicators in each grade level? As mentioned above, we have found the expectation scores of

Table 1. The Averages of Students' Aggregate score $\overline{w}$

Grade	7th	8th	9th	10th
$\overline{w}$	0.3762	0.3665	0.6205	0.6985

each grade level. Since the expectation score of a grade level is the ideal average score of the population of that grade level, it is reasonable to set it as the ideal standard for the specified grade level. These expectation scores are $E(\tilde{G}_6)=0.0667$, $E(\tilde{G}_7)=0.2$, $E(\tilde{G}_8)=0.4$, $E(\tilde{G}_9)=0.6$, $E(\tilde{G}_{10})=0.8$, and $E(\tilde{G}_{11})=0.9333$.

Since the learning progress indicator for the 7th-grade is 0.3762 that is higher than $E(\tilde{G}_7)=0.2$, it means that the average performance of the 7th-grade subjects in our study is better than the ideal average performance of the population of 7th graders. Moreover, suppose that our study takes a survey and the learning progress indicator of the 7th-grade is also 0.3762, it can say that the average performance of the 7th-grade students in Taiwan is better than what we have expected. Also, the same approach can also be applied to 8th-grade, 9th-grade, and 10th-grade students.

One strange situation we need to elucidate is that the learning progress indicator of the 7th-grade students is higher than the learning progress indicator of the 8th-grade students in our study . Although the performance of the 8th-grade students is a little bit lower than the ideal standard, it is acceptable. Thus, we can see that the causes of this situation come from the 7th-grade students. We think that there are two main reasons. The first reason is that there were only two 7th-grade sample classes in our study. If one of the classes has an extreme average score, it would affect the result greatly. In fact, one of the sample classes had an average score of 0.398 that is closed to $E(\tilde{G}_8)=0.4$. In this case, we would prefer to believe that the abilities of this class are above average. The second reason is that the concept of triangles is involved in 7th-grade, but not in 8th-grade school mathematics curriculum. So, it is expected that the learning progress indicators of the 7th-grade and 8th-grade will be close together.

2. Learning Progress Indicator of a Group with an Unknown Grade Levels

Suppose that we have a class H, with unknown grade level between 7th-grade and 10th-grade, and we want to forecast its grade level. The distribution scores of the students in the class are shown in Table 2.

Table 2. The Distribution Scores of Students in Each Score Interval (in Percentage)

Score Interval	H
$0.0 \le x < 0.1$	0
$0.1 \le x < 0.2$	0
$0.2 \le x < 0.3$	4.94
$0.3 \le x < 0.4$	7.41
$0.4 \le x < 0.5$	13.548
$0.5 \le x < 0.6$	13.58
$0.6 \le x < 0.7$	19.75
$0.7 \le x < 0.8$	30.86
$0.8 \le x < 0.9$	9.88
$0.9 \le x < 1.0$	0

According to the membership functions, the strong 0-level sets of each grade level are $\tilde{G}_7=\{x\in[0,\ 1] \mid \mu_{\tilde{G}_7}(x)>0\}=(0,\ 0.4)$, $\tilde{G}_8=(0.2,\ 0.6)$, $\tilde{G}_9=(0.4,\ 0.8)$, and $\tilde{G}_{10}=(0.6,\ 1)$. If H is a 7th-grade class, then we can say that only 12.35% (=0+0+4.94+7.41) of its students are in the right grade and 87.65% of students are in an upper grade. If H is a 8th-grade class, then we can say that only 39.51% of its students are in the right grade and 60.49% of students are in an upper grade. If H is a 9th-grade class, then we can say that 77.77% of its students are in the right grade, 9.88% of students are in an upper grade, and 12.35% of its students are in a lower grade. If H is a 10th-grade class, then we can say that 60.49% of its students are in the right grade and 39.51% of its students are in a lower grade. From the discussions, it is clearly that the class H is more likely to be a 9th-grade class. In fact, the data in Table 2 comes from all the 9th-grade subjects in our study.

3. Learning progress Indicator of a student.

From section III, we have a student whose score is 0.64445. Substitute this value into the membership functions, we have $\mu_{\tilde{G}_6}(0.64445)=0$, $\mu_{\tilde{G}_7}(0.64445)=0$, $\mu_{\tilde{G}_8}(0.64445)=0$, $\mu_{\tilde{G}_9}(0.64445)=0.77775$, $\mu_{\tilde{G}_{10}}(0.64445)=0.22225$, and $\mu_{\tilde{G}_{11}}(0.64445)=0$. These data tell us about the student's membership degrees in each grade. Clearly, this student is not likely to be in 6th-grade, 7th-grade, 8th-grade, or 11th-grade. Since $0.64445\in\tilde{G}_9$, it suggests that this student's grade level should be 9th-grade. But, we should not neglect the fact that $\mu_{\tilde{G}_{10}}(0.64445)=0.22225$. It indicates that the learning progress of this student is moving from 9th-grade to 10th-grade. Although, this student's learning progress is not good enough to be a 10th-grade student, he/she is a 10th-grade student. This result is still reasonable because her/his score is $0.64445\in\tilde{G}_{10}=(0.6,\ 1)$.

V. Conclusions

Although it seems that the algorithm is so complicated in establishing the 'fuzzy' learning progress indicators, we can easily setup a computer software as a useful routine procedure to do the algebraic manipulations, as same as what we have done in this study. Contrarily, it is worth of doing such complicated manipulations since the approach provides a wealth of hints about students' learning progress. Moreover, we will try to discuss some advantages of using the 'fuzzy' learning progress indicators.

1. In our 'fuzzy' learning progress indicators, we have some ideal standards as the reference points to compare with the indicators. In the traditional approach, it is not known what the ideal reference points are. Thus, after we combine the raw scores, we still cannot draw any conclusion about students' learning progress. For example, the average of the sum of raw scores of the 10th-grade students in our study was 31.5547. If we divide it by the maximum possible score of 40, we obtain the value of 0.7889. What does this value tell us? It just indicates that, on average, the 10th-grade students had 78.89% of the questions correct. Is it good enough to be a 10th-grade class? No one knows.
2. Someone may think that they can also set the reference points, such as 80% for 10th-grade students in the traditional approach. We may ask "What is the relationship between the reference points and the indicators (the combined scores)?" If there is no connection between them, then we may set the reference points as what we like. To illustrate the risk associated with it, students who have not truly been in the 10th-grade will be thought to be in the 10th-grade, or students who are in the 10th-grade will be thought not to be in the 10th-grade. This defect makes the indicators useless.

Although the reference points were set prior to the test, there is a strong connection between them and our 'fuzzy' learning progress indicators. When we derive the indicators from the raw scores, the reference points (the expectation values of each grade) are concerned in the algorithm. Moreover, these reference points do not change over time. So, the reference points and the indicators are strongly linked on in our approach.

3. As we mentioned above, the second interpretation method involves comparison of a given indicator with its value at some prior time. Suppose that we have two values of an indicator, one for the last year and the other for this year, then how can we compare these two values? No one knows which one is better because the cause of difference may be due to the difficulty of the tests or other factors. But no matter how the situation changes, the reference points of the indicator are the same in our approach since the reference points of the indicator do not change over time. Therefore, it is reasonable to compare the two values to see which one is better.
4. It is widespread agreement that the purpose of mathematics achievement tests is to try to finger out students' knowledge of mathematics. In fact, a student getting 0 point on a subconcept does not mean that he/she knows nothing about that concept. Also, a student getting maximum points on the subconcept does not mean that he/she knows everything about that concept. Thus, using the expectation values in our approach is better than using the original scores in the traditional approach.

Appendix

The triangular membership functions $\mu_{G_6}(x)$, $\mu_{G_7}(x)$, $\mu_{G_8}(x)$, $\mu_{G_9}(x)$, $\mu_{G_{10}}(x)$ and $\mu_{G_{11}}(x)$ are as follows:

$$\mu_{G_6}(x) = \begin{cases} 1-5x & 0 \le x \le 0.2 \\ 0 & 0.2 < x \le 1 \end{cases}$$

$$\mu_{G_7}(x) = \begin{cases} 5x & 0 \le x \le 0.2 \\ 2-5x & 0.2 < x \le 0.4 \\ 0 & 0.4 < x \le 1 \end{cases}$$

$$\mu_{G_8}(x) = \begin{cases} 0 & 0 \le x \le 0.2 \\ 5x-1 & 0.2 < x \le 0.4 \\ 3-5x & 0.4 < x \le 0.6 \\ 0 & 0.6 < x \le 1 \end{cases}$$

$$\mu_{G_9}(x) = \begin{cases} 0 & 0 \le x \le 0.4 \\ 5x-2 & 0.4 < x \le 0.6 \\ 4-5x & 0.6 < x \le 0.8 \\ 0 & 0.8 < x \le 1 \end{cases}$$

$$\mu_{G_{10}}(x) = \begin{cases} 0 & 0 \le x \le 0.6 \\ 5x-3 & 0.6 < x \le 0.8 \\ 5-5x & 0.8 < x \le 1 \end{cases}$$

$$\mu_{G_{11}}(x) = \begin{cases} 0 & 0 \le x \le 0.8 \\ 5x-4 & 0.8 < x \le 1 \end{cases}$$

References

Bezdek, J. (1981). Pattern recognition with fuzzy objective function algorithms. New York, London.

Chanas, S. (1982). Fuzzy sets in few classical operational research problems. In Gupta and Sanchez, 351-363.

Kastner, J. & Hong, S. (1984). A review of expert systems. EJOR 18, 285-292.

Kaufmann, A. & Gupta, M. (1991). Introduction to fuzzy arithmetic theory and applications . Van Nostrand Rienhold: New York.

Kickert, W. (1978). Fuzzy theories on decision-making. Leiden: Boston, London.

Law, C. K. (in press). Using fuzzy numbers in educational grading system. International Journal for Fuzzy Sets and Systems.

Murnane, R. & Raizen, S. (1988). Improving indicators of the quality of science and mathematics education in grades K-12. Committee on indicators of precollege science and mathematics education, National Research Council. Washington, D. C. : National Academy Press.

Shavelson, R., McDonnell, L., Oakes, J. , & Carey, N. (1987). Indicator systems for monitoring mathematics and science education. R-3570-NSF. Santa Monica, California: Rand Corporation.

Shavelson, R., McDonnell, L., & Oakes, J. (1989). Indicators for monitoring mathematics and science education. A sourcebook. R-3742-NSF/RC. Santa Monica, California: Rand Corporation.

Smithson, M. (1987). Fuzzy set analysis for behavioral and social science. New York.

Zadeh, L. (1965). Fuzzy Sets, Information and Control, 8, 338-352.

Zimmermann, H. (1991). Fuzzy Set Theory and Its Applications, Second Revised Edition. Kluwer Academic Publishers: Boston, Dordrecht, London.

使用模糊數學理論建立數學學習進展指標

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摘　　要

有鑑於近年來我國教育改革如火如荼的展開，我們極需建立一套教育指標，來評定教育改革的成效。美國CIPSME(Committee on Indicators of Precollege Science and Mathematics Education)建議：任何教育指標之建立，應優先考慮學習進展指標之建立。又因社會大眾和決策單位大都使用學生的學習成就來評定學生學習進展的成效，因此如何評量學生的學習成就顯得特別重要。故此，本研究嘗試利用模糊數學理論，分析樣本學生的測驗成績，藉以建立國中數學概念的學習進展指標之評量計算模式。

進一步，本研究將提供一實際例子來說明此一評量計算模式及其演算法。在實際例子中，本研究透過大慧調查法擬定一評測問卷，其中包含40題以三角概念爲主題的選擇題進行研究。樣本學生爲大台北四所學校，其中包括國一、國二、國三和高一共359學生。另外，本研究也透過此一例子，示範如何解釋及如何應用所獲得的相關訊息。

因此，本研究主要目的有：以模糊數學理論，發展具有信度、效度的工具，以期協助我國國中數學概念學習進展指標之建立；提供如何解釋及如何應用此數學學習進展指標的相關訊息，讓教育決策單位能透過此指標來擬定適當的教育政策之參考。

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Logic through Mathematical Reasoning as a General Education Course*

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ABSTRACT

The purpose of this study is to design and investigate a general educational mathematics course to bridge between humanities and social science scholars on one hand, and natural scientists and engineers on the other. From several possible courses, I finally selected one on logic from the point of view of Boolean algebra. I discuss the syllabus, student feedback, and also give a few guidelines for designing general educational courses in mathematics.

Keywords: Logic, mathematical reasoning, general education course.

I. Why Offer a Course on Logic through Mathematical Reasoning?

At the end of the Second World War, Taiwan was basically an agricultural country, with more than half the population working as farmers. After half a century of hard work, Taiwan is now on the threshold of becoming a developed country. During the development stage, what was needed for college education was a quick grasp of modern technology in order to industrialize the country. This purpose was achieved in less than half a century. Now the country has become affluent, and college curriculum reform is needed to meet the spirit of society during a new era. We still need experts in various specialized technical fields to maintain the country's economic well-being; but, more urgently, we want to educate our citizens to nurture a global point of view, an orderly mind and a warm and generous heart. Mr. Wu Ta-you (吳大猷), former president of Academia Sinica, said [in Wu 1986] that "The meaning or ideal of general education lies in making a man know his national history and social problems; appreciate philosophy, literature and art; and understand the basic parts of science, its development, methodology and spirit, so that he has the power and habit to analyze objectively all kinds of events." The institution of a general education program is just to serve this purpose.

C. P. Snow used to explain the phenomenon of the cold war in terms of two cultures [Snow 1962]. This schism between two cultures still persists in the present-day academic world; because the group of humanities and social science scholars and the group of natural scientists and engineers still cannot talk to each other, a bridge between them must be constructed. The purpose of this study is to design and investigate a general education course aiming to be such a bridge. We have set up three conditions for the course to meet: We want our students (1) to appreciate what students in the other group do; (2) to develop an orderly mind; and (3) to receive part of the cultural heritage our ancestors handed down to us.

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As a mathematician, I would like to design such a course in mathematics and related areas. First let us review two general education courses in mathematics offered in Taiwan. Some seven years ago the Department of Mathematics at National Central University offered a course called "General Education Mathematics," which was a combination of 7 unrelated mini-courses which each lasted four hours, and each of these mini-courses was given by one of the faculty members in a subject selected by himself. The only criterion for preparing the course material was that it be as elementary as possible, so that most students in the class could understand. Since there was neither coordination nor interaction between the mini-courses, and since there was little chance for the instructors to assign work home exercises, which are quite essential to the understanding of elementary mathematics, I cannot say that the course was successful.

A second course was given by Professor Huang Min-huang (黃敏晃) at National Taiwan University under the title of "Mathematical Games." In this course Professor Huang presented various mathematical principles by means of games. One example he related to me was that, from statistical data cited in a newspaper, the class tried, using basic statistical principles, to guess the population of a certain community in Taipei County. After having made a guess, they phoned the local authorities to find out the true population. Their guess turned out to be rather close.

In addition to these courses which were actually given, some other candidates for general educational mathematical courses should also be mentioned. One possible course is "Mathematical Experiments." Professor Chuan Jen-chung (全任重) taught such a course at National Tsing Hua University, not as a general education course, but as a course to train professional mathematicians. Using computers to avoid tedious computations, the students were asked to experiment on various mathematical problems and make sensible conjectures. After making these conjectures, the students sought to prove them. The purpose of this course was to create new mathematical theorems. Currently Professor Hua Yang (華洋) and the author are planning a similar course for social science students at National Central University, and selecting a different set of experiments, with the purpose not of creating new mathematical theorems, but of grasping difficult mathematical concepts. Thus "Mathematical Experiments" may be adapted to the general education course level.

But none of these courses meets all three requirements. We need not discuss the first course, which in any case failed. As for the mathematical games, this may easily degenerate into recreational mathematics and "nutritional credits." Furthermore, instructive mathematical games are hard to find. As for mathematical experiments, these are still in the formative stage, and are one-sided, good for social science majors only, but not appropriate for science and engineering majors.

I have considered several other courses. The first possibility is a calculus course from a general educational approach. In other words, it should be a course teaching calculus from the point of view of the development of thought of mankind, together with some applications. But such a calculus course would probably be too difficult for students with a humanities background, yet not deep enough to meet the needs of science and engineering majors. To implement such a course, we would have to reorganize the university: all students would take only general education courses during their freshman and sophomore years, and select various specialized majors after the junior year. This might be a good system, and quite a number of local mathematicians would approve of it. But educational reform will be gradual; this can be one of our goals, and we may hope that some day this goal will be reached.

Another possibility is "Elementary Number Theory." For anybody with a mathematical inclination, number theory is like a treasure trove. When studying number theory, one would like to shout "Eureka" repeatedly. But, with the exception of the simplest part of number theory, which has applications in computer science, the more advanced theory is not applicable at all. In this commercially-oriented society, utilitarianism is in vogue, and the "art for art's sake" or "mathematics for mathematics' sake" attitude seems to be unacceptable to the "younger generation".

I have also considered Euclidean plane geometry. This was a standard part of the high school curriculum some twenty years ago. With the exception of the Bible, no book was published in more editions than Euclid's Elements. But, after the "New Math" period, this course with its almost perfect logical organization disappeared from the Taiwan syllabus, although many parts pop up now and then in high school texts in a disorganized way. Thus this course would not stimulate the students with any fresh impact, and is therefore not a good choice for a general education course.

After these considerations, I finally decided on a logic course. Professors Chen Wen-hsiu (陳文秀) and Lin Chao-tien (林照田) of National Taiwan University also considered the possibility of designing a general education course in logic [See Chen 1994 and Lin 1993]. But the course they discussed would be taught from the point of view of the humanities, and would not meet our three requirements. Our course discusses elementary logic from the point of view of Boolean algebra. It spans the fields of mathematics, philosophy and computer science, and is useful both in the training of orderly thinking and in practical applications. In this course we introduce to the students such concepts as classical syllogisms, basic set theory, construction of algebraic systems, selection of canonical forms, isomorphism and representation, and logic in digital computers, etc. Furthermore, since the material was never touched in the high school curriculum, it maintains its freshness for most students. Therefore I believe that it is a very suitable choice.

The course was given twice during the 1993/1994 academic year, and lecture notes were used. These lecture notes were transformed into a book [Wang 1994] during the summer of 1994, and the course was again taught in the 1994/1995 academic year. As ideas whose time has come are often conceived by several people nearly simultaneously, I was told last June, in a conference on general education, that there was a similar course given at Tunghai University by Professor Kwang Chi-jen (鄺芷人), who also wrote a similar book [Kwang 1993]: After checking Mr. Kwang's book, I found that his and mine are complementary.

II. Sketch of the Course

Although the course changes each time it is given, we shall sketch the course by summarizing its textbook. At the very beginning are six anecdotes concerning logic. One of these is the following:

> In the Black-White Village there lived two races, the Blackfoot, who always tell lies, and the Whitefoot, who never tell lies. One day a stranger came to the village to visit the Black-White Temple. At a fork in the road, he saw a farmer and be wanted to ask which of the two branches of the road would lead to the Temple. Unfortunately the farmer stood in a rice paddy and he could not see the color of the farmer's feet. With one yes/no question, he determined which road was the correct one. Can you figure out what he asked?

The answer is: If I ask somebody whose feet has the same color as yours whether the left branch of the road leads to the Black-White Temple, what would be his answer?

This book is spotted with quite a few such anecdotes to rouse the interest of the student. Afterwards we begin the course with Aristotelian syllogisms and modern set theory. The four kinds of propositions are put in set theoretical notation as follows:

A: Universal affirmative: "All X are Y". $X \subset Y$.
I: Existential affirmative: "Some X are Y". $X \cap Y \neq \phi$.
E: Universal negative: "All X are not Y". $X \cap Y = \phi$.
O: Existential negative: "Some X are not Y". $X \backslash Y \neq \phi$.

These four propositions are denoted by XaY, XiY, XeY and XoY respectively. A *syllogism* is a deduction connecting three terms S, M and P. It consists of three propositions: the *major premise*, which is a connection between M and P, the *minor premise*, which is a connection between S and M, and the *conclusion*, which is a connection between S and P. The idea is that whenever the two premises are valid, the conclusion must always be true. There are four figures of syllogisms, which in the order of major premise, minor premise and conclusion, are respectively:

Figure I: *MrP*, *SrM*, *SrP*;
Figure II: *PrM*, SrM, SrP;
Figure III: *MrP*, *MrS*, *SrP*;
Figure IV: *PrM*, *MrS*, *SrP*;

where each *r* may be *a*, *i*, *e* or *o*.

According to the ancient Greeks, there are 19 valid syllogisms:

4 in Figure I: AAA, EAE, AII, EIO.
4 in Figure II: EAE, AEE, EIO, AOO.
6 in Figure III: AAI, IAI, AII, EAO, OAO, EIO.
5 in Figure IV: AAI, AEE, IAI, EAO, EIO.

In this list the three letters for each syllogism denote the proposition types of the major premise, the minor premise and the conclusion, in that order. Thus AEE in Figure II can be expanded to

Major premise: PaM. All P are M.
Minor premise: SeM. All S are not M.
Conclusion: SeP. All S are not P.

All these syllogisms can be discussed in terms of set theory. Thus the syllogism AEE of Figure II says that if $P \subset M$ and $S \cap M = \phi$ then $S \cap P = \phi$. This is quite clear, since when the larger set M has no common element with P, so must also the smaller set S.

Some parts of the classical theory become transparent through the set theoretical presentation. Thus conversion is a simple consequence of the commutative law of set theoretical intersection, and obversion depends on the properties of the complement. Also, some syllogisms in the above list are seen to be invalid, if validity means having universal premises and existential conclusions. Thus the syllogism AAI in Figure III is invalid, as the following example shows:

MaP: All triangular squares are triangular.
MaS: All triangular squares are squares.
SiP: Some squares are triangular.

The trouble lies in the fact that the set of triangular squares is empty.

The second main topic we study is propositional calculus. Here we consider a simple proposition as a Boolean variable, i.e., a variable which takes on the two values 0 (or false) and 1 (or true) only. A composite proposition is a Boolean-valued function of number of Boolean variables. The following Boolean functions are basic in our discussions:

$\neg p$	not p.
$p \wedge q = pq$	p and q.
$p \vee q$	either p or q (or both).
$p + q$	either p or q but not both.

The operation $p+q$ is called the "exclusive or". Our notation reflects addition in modulo 2 arithmetic.

There are exactly 2^{2^n} Boolean functions in n Boolean variables, and we would like to find some standard way to represent them. In most books on logic or Boolean algebra, a canonical form in terms of $\neg$, $\wedge$ and $\vee$ is given. But we give a new canonical form, in terms of addition and multiplication, so that this canonical form reflects polynomial representation in algebra. Thus, by a *Boolean monomial* we mean a product of 1 with a number of distinct Boolean variables, and by a *Boolean polynomial* we mean a sum of 0 or more distinct Boolean monomials. Every Boolean function in n Boolean variables can be represented as a Boolean polynomial; and, if two Boolean monomials with the same factors but different orders of arrangement are considered equal, and if two Boolean polynomials with the same terms but different orders of arrangement are also considered equal, then this representation is unique. This canonical form was known to Dickson at the beginning of this century, in different contexts. To adapt it to logic seems to be new.

The Boolean functions x, y, z with respect to the operations $\wedge$ and $\vee$ satisfy the following conditions:

Commutative laws: $x \vee y = y \vee x$, $x \wedge y = y \wedge x$.

Associative laws: $x \vee (y \vee z) = (x \vee y) \vee z$, $x \wedge (y \wedge z) = (x \wedge y) \wedge z$.

Distributive laws: $x \vee (y \wedge z) = (x \vee y) \wedge (x \vee z)$, $x \wedge (y \wedge z) = (x \wedge y) \vee (x \wedge z)$.

Absorption laws: $x \wedge (x \vee y) = x$, $x \vee (x \wedge y) = x$.

Identity elements: There are two elements, 0 and 1, such that

$$0 \vee x = x, \quad 0 \wedge x = 0, \qquad 1 \wedge x = x, \quad 1 \vee x = 1.$$

Complementary elements: For every element x there is an element y such that

$$x \vee y = 1, \quad x \wedge y = 0.$$

y is called the *complement* of x. It will be denoted by $\neg x$ or x'.

Any set A, in which there are defined two operations $\wedge$ and $\vee$ such that the conditions above are met by any three elements x, y, z of A, is called a *Boolean algebra.*

Several other operations may be defined in terms of these Boolean algebra operations. Thus, the *exclusive* or may be defined as

$$x+y=(x\wedge\neg y)\vee(y\wedge\neg x).$$

The statement "if x then y", in symbols, $x\to y$, may be defined as

$$x\to y=(\neg x)\vee y.$$

A *tautology* is a Boolean function which has the value 1 no matter what values we assign to its variables. Thus

$$((p\vee q)\wedge(p\to r)\wedge(q\to r))\to r$$

is a tautology. This means that the time-honored dilemma argument is valid. Thus, both the statement

> "If the price of rice is high, then the farmers are glad. If the price of rice is low, then the people are glad. Hence the rice price control official is always praised."

and the statement

> "If the price of rice is high, then the people are hurt. If the price of rice is low, then the farmers are hurt. Hence the rice price control official is always blamed."

are valid arguments. The lesson of this might be that price control is foolish, and the price should be under the influence of the free market only.

Some say that there is no need of symbolic logic, since logical arguments always come out naturally. As a reply to these people, let's look at the following computation:

$$\begin{aligned}
&(p\wedge q)\to r\\
&=[\neg(p\wedge q)]\vee r\\
&=(\neg p)\vee(\neg q)\vee r\\
&=(\neg p)\vee(\neg q)\vee r\vee r\\
&=[(\neg p)\vee r]\vee[(\neg q)\vee r]\\
&=(p\to r)\vee(q\to r).
\end{aligned}$$

This says that the statement

> "If you run out of gas and you stop on a toll bridge, then you are fined."

and the statement

> "Either if you run out of gas then you are fined, or if you stop on a toll bridge then you are fined."

are equivalent. Do you think that this equivalence would emerge naturally?

We indicated that the set of all Boolean functions in n Boolean variables forms a Boolean algebra. Another example is the set of all subsets of a given set, under the operations of $\cap$ and $\cup$. Let A and A′ be two Boolean algebras. If there is a one-to-one correspondence $x\to x'$ between them such that $x\wedge y\to x'\wedge y'$ and $x\vee y\to x'\vee y'$, then these two Boolean algebras are called *isomorphic* to each other, and the one-to-one correspondence is called an *isomorphism*. Two Boolean algebras which are isomorphic to each other may be considered the same Boolean algebra under different notations. Their algebraic properties are identical.

It would be very nice if, for an abstractly given algebraic system, we may find a concrete model isomorphic to it. This is the case for finite Boolean algebras. In fact, for any finite Boolean algebra A there is always a finite set T such that A is isomorphic to the Boolean algebra formed by all subsets of T, with set theoretical operations. This is a fairly deep theorem, and is the deepest theorem in the book [Wang 1994]. It is proved by studying the structure of finite Boolean algebras; specifically by studying their atoms. Anybody who is interested in the proof may consult the book.

Finally, there is a discussion of the notation of numbers in general, and the binary, octal and hexadecimal notations in particular. Boolean algebra techniques are then incorporated into binary arithmetic, which is the basic tool for constructing digital computers.

III. Experimental Teaching

The course was taught three times, all at National Central University. The first experimental offering was given during the fall semester of 1993. Since no lecture notes were prepared in advance, at the beginning of each class session we handed out lecture notes which summarized what we had talked about last time. Near the end of the semester when I reached the conclusion of the course, I found that there were still four lecture hours left unused. I had to add some topics on modular arithmetic to fill up the time. In order to avoid repeating this embarrassing situation, I later added the subjects of conversion and obversion the second time the class was offered.

The only restriction on the course was that no math and E. E. majors were allowed. I wished to have more humanities-major students, but this wish did not come true. In the end we had 26 students from science departments, 12 engineering students, 15 from business administration and 3 from the humanities. Since the mathematical backgrounds of the students were diverse, it was very difficult to control the pace of the syllabus. One humanities student complained on his final examination that the course was impractical, but one science major tole me in person that the course was useful.

Toward the end of the semester, we sent out an advertisement to all the departments in the School of Humanities, asking students to come to an explanation session for the same course to be given during the next semester. But when the time arrived, no students came to attend the lecture. This shows the aversion toward mathematics felt by students in the humanities.

After the first draft of the lecture notes had been completed, I sent it out to several mathematicians and several professors in various departments interested in general education, and invited them to submit their opinions. The following were their suggestions:

1. Different sections of the course should be given to students with different mathematical backgrounds. Those who the joint college entrance examination took the science-oriented mathematics test should be given a deeper course than those who took the humanities-oriented mathematics test.
2. The same textbook may be used for both sections of the course, with different emphases in different classes.
3. Because it has a philosophical flavor, this course is not strictly a general education course in mathematics, and therefore should also be open to mathematics majors.
4. Many E. E. majors think that logic is something which lies in the gates of computer circuits. They should also study the original meaning of logic.
5. Mathematical terms such as atoms, rings, fields, etc. have different meanings from the everyday usage. This should be mentioned in the preface of the book.

In addition many suggestions on French grammar, Chinese literature and physics were also given. All these suggestions and improvements were later incorporated into the lecture notes when the course was taught the second time.

During the spring semester of 1994, the course was offered a second time. The number of students this time was considerably less: 15 science majors, 10 engineering majors and 5 business administration majors. We again handed out lecture notes at the beginning of every class session.

National Central University began adopting a new set of course requirements in the fall semester of 1994. The freshmen starting in this academic year were required to take 8 credits of general education courses. The courses were classified into three categories: humanities, social sciences and science and technology. Each student was required to take 4 credits outside of their primary category, and 4 credits without any restriction. Thus, a science major must take 4 credits in either humanities and/or in social science. The effects of this requirement were not so apparent in the first year, but will certainly show up in the years to come.

The course Logic through Mathematical Reasoning was offered a third time in the fall of 1994. It was classified as a humanities course the first time and science and technology the subsequent time. This time we got 12 science majors, 21 engineering majors and 16 business administration majors. Another change was that the textbook was published, so the students did not have to pick up lecture notes during each class. Unfortunately, this caused many students to cut class since they thought they could study the textbook on their own.

IV. Student Feedback

Each time the course was offered, we handed out a questionnaire to each student during the last hour of class, asking him or her to write comments concerning the course. The following is a summary of what we learned from these questionaires:

1. Among the students, around half took the course out of interest, and the other half out of curiosity.
2. Most students though the pace of teaching was

about right or too fast.

3. The science and engineering students thought the level of difficulty of the course was about right, but the humanities and business administration students thought the course was too difficult. This shows that the mathematical preparation of the business administration students was not as good as I had thought.
4. When asked what is the most suitable general education mathematics course, less than half selected this one. The other answers were varied, and included calculus, mathematics for engineers, etc. This shows that they misunderstood what general education is for.
5. A few samples of other comments are listed below:
   - Syllogisms, Boolean algebras, and binary representations will be useful to my computer programming techniques.
   - This course was helpful for English composition. But since not many English majors are taking this course, I can hardly find anyone to consult with after having troubles with the course.
   - This course showed us the interdependence between mathematics and logic. Many simple logical anecdotes in the course are interesting.
   - Except for syllogisms and sets, such topics as Boolean algebras, rings, and functions are hard to understand, too mathematical, and useless.
   - Part of the course was too theoretical. Please do away with the proofs and keep the interesting part only.
   - The part on Boolean algebra was difficult, and the teacher should spend more time on it. Spend less time on the easier part of syllogisms, etc.
   - Only the principles of binary arithmetic were mentioned, but not the actual logical design of computers.
   - A general education course should touch all the major subjects of the students. The term paper of a civil engineering student, for example, should be on a subject relating the course to civil engineering.
   - When talking about mathematical theories, please mention the historical development of these ideas, and the biographies of mathematicians. These, together with mathematical games, will strengthen participation in the course.
   - To attract humanities students, add more propositional logic, and discuss logical mistakes through concrete examples.
   - Basically this course is too difficult for humanities students. To solve this problem, a section of this course should be devoted to them only.
   - Give more explanations for the mathematical terms and their applications.
   - I cannot find relevant references in the library. Please give a reference list at the beginning of the course.
   - A general education mathematics course should include the following topics: magic squares, statistics of poker games, infinite sets, Cantor sets etc., and the influence of mathematics on other sciences.
   - Homework was not sufficient.

Note that problems mentioned in several of these comments were solved when the course was given in two different sections.

V. Guidelines for Designing General Education Mathematics Courses

Although my experience at designing general education courses is limited, and although this course, *Logic Through Mathematical Reasoning*, is not strictly a mathematics course, I would still like to summarize my experience into a few guidelines for designing other general education courses in mathematics and other sciences.

First, the two-culture thesis of C. P. Snow is not groundless. Students in humanities feel an aversion to courses in science, and students in business administration are not mathematically prepared. For professors in science and engineering departments, these facts must be taken into primary consideration. Unless the system of joint college entrance examinations is overhauled, never try to incorporate students with diverse backgrounds into one class. There is a difference between planning the course and writing a textbook for it. The same textbook may be used for several classes, each with a different background, with different emphases in each of the classes.

The selection of the topic is rather difficult. As a general education course, it must be relevant to life. Mathematics is a impersonal science, and all it can offer is logical thinking. The designer of the course must always bear this in mind. Many forms of the course could be adopted: lectures, preview and discussion, games, etc. But no matter what route you take, it must be mainly a course in training orderly logical thinking.

After the topic has been selected, it is advisable to select a textbook if one is available. As general education textbooks are rare, most likely you will need to write a textbook on your own. This is a tedious and heavy task, though it may also be rewarding. If this is what you decide to do, my advice is that you don't publish it until you have taught it a couple of times, incorporating into it comments from students and peer professors. Needless to say, the course as well as the textbook should be reviewed from time to time.

In local student slang, a course with "nutritional" credits is one which has no substantial content and in which it is easy to get high grades without much effort. It is thus nutritional to the student's grade average. A general educational course may be easily misconstrued as nutritional by the student in this sense. What we need is in fact a course nutritional to his intellectual development.

References

Chen Wen-Hsiou (1994) Logic and general education. (Chinese) *Chehsüe Lunping*. Issue 17; revised version published in *General Education Quarterly*. **1**(3), 33-52.

Kwang Chi-yen (1993) Proposition logic and Boolean algebra. (Chinese) Wenchin Publushing Co.

Lin Chao-tien (1993) Sketching the fundamental importance of logic - as viewed from its coverage, systematicity and applicability. (Chinese) *Conference on Philosophy in General Education*. National Taiwan University, Apr. 16-18.

Snow C. P. (1962) The two cultures and the scientific revolution. New York, Cambrideg University Press.

Wang Ju-kwei (1994) Logic and Mathematical Reasoning. (Chinese) Fan-yi Publishing Co.

Wu Ta-you (1986) Educational Problems. (Chinese) Yuan-Liu Publishing Co.

通識課程「邏輯與數學思維」的設計

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摘　要

人文社會方面的學者與理工學院的學者可謂形成兩個不同的文化集團。本研究的目的是設計一項通識數學課程，以建立兩文化集團間的橋樑。從幾種不同的課程中，我選擇了本課程—以布爾代數的觀點看邏輯。本文討論課程設計、學生回饋、以及幾項設計這類通識數學課程的訣竅。

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A Model for Design Education

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ABSTRACT

For years the design departments of various levels of vocational and technological schools have separately developed unique design teaching methods and trained many personnel to meet the demands of various industries in Taiwan. Their achievements must not be forgotten. Therefore this study has taken these existing design education methods as base and adopted some of the strengths of foreign design education systems. This paper has investigated four aspects of design education, namely design curriculum, case study methods, cooperative work programs between industry and education, and practicum systems. Firstly, background material and objectives of this study were explained. Secondly a brief review of design education in Taiwan was conducted. Thirdly, up-to-date alternatives in these aspects were discussed. Finally, a design center serving to coordinate functions among the subjects under study was proposed and set up as a foundation for further exploration. Findings of this study were also summarized in a condensed form.

Key words: Practical design, professional Ability, educational models, design education.

I. Introduction

1. Background

Various levels of vocational and technological institutions have played important roles in the rapid economic and industrial development of recent years in Taiwan. Now an urgent problem facing us is how to improve and renovate the vocational and technological education system to educate and train specialists and professionals needed by the present socioeconomic environment. The development of the vocational and technological education system (VTES) is now facing a tremendous shock that has never been experienced before(Chiang, W. H. 1993) [1]. The institutes of technology or technological universities are meant to educate and train needed specialists and professionals for the needs of current and future society. They are leaders in the professional education system and their reactions to this problem are the focus of attention for all sectors of the society.

It was pointed out in the manpower development report of the 10th Taiwan Economic Construction Mid-term Plan that the future manpower demand structure will grow more in the service sector (Council for Economic Planning and Development, CEPD, 1990)[1]. A study of domestic institutes of technology has indicated that manpower allocated to design departments still seemed insufficient (LIN, C. C. 1991) [2].

It was also emphasized in the long-term national science development plan that the development of scientific technology for the next 12 years must integrate limited scientific resources and adopt a market-oriented strategy to actively develop production technology (National Science Council, NSC 1992)[1]. Main strategies include enhancing quality of college and university research, reinforcing the vocational and technological education system consisting of colleges and institutes of technology, emphasizing planned di-

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vision of labor, linking technological resources of upstream and downstream industries, cooperating in R & D, accelerating commercialization of R & D results and increasing added value to enhance industry's ability to compete in the marketplace.

The advancement of Taiwan's machine industry will depend on gain of independence in product design, which needs strong R&D support [8]. All in all, the demand for industrial design talent is strong. Therefore,the urgent need to improve and strengthen that educaion of design students is obviously an important consideration for technological university education in the near future .

2. Objectives

In view of the present status of technological university education, reference will be made to the progress and improvements achieved by domestic research and development as well as the merits of foreign research and experience. This study incorporates the opinions of professionals and experts in both industry and academia, and conceptualizes design education models that will meet the challenge of the 21st Century. Therefore, the main objectives of this study are as follows:

(1) Study of an integrated and unified curriculum plan.
(2) Design and development of case studies as teaching methods.
(3) Study of the feasibility of implementing a practicum or intern system.
(4) Establish a plan for cooperative work experience.

It is hoped that by updating selected design curriculum and teaching methods, and implementing a practicum or intern system, the model can produce capable professional designers to meet the demand for domestic R&D in the special environment of Taiwan.

II. Design Education in Taiwan

Within the current school system, each individual requires nine years of compulsory education before entering into high school or senior vocational school. It is, more often than not, at this high school level that many design-related courses and programs are established to develop students' sense and skill of design. In other words, after nine years of compulsory education, a student can plan his own study either through the VTES or the general education system. The VTES includes senior vocational schools, junior colleges and technological institutes or universities. The *senior vocational schools* are aimed at educating skilled workers, while the *junior colleges* are to educate technicians as their primary objective. The *technological institutes or universities* are aimed at educating high-level professional specialists. On the other hand, the (traditional) general education system includes *senior high schools and colleges or universities*. Although two systems emerge at the collegiate level within the higher education stage, their educational objectives are somewhat different in their nature.

Broadly speaking, one of the primary purposes of the VTES is to provide talented manpower for the nation. This is a long term investment in order to lay a solid fundation for the nation's future development. Design education, under the R.O.C.'s construction plan, is one of the most important tasks to be implemented. The main objective of educating designers at the college level is to meet the growing demands of the global economic environment. For over three decades, design education in Taiwan has provided numerous professional designers to various sectors of industry. As international markets open up for free competition, it is apparent that the economy has to shift from a traditionally labor-intensive production model to a model that emphasizes the value of intellectual property and the ability to design products independently. Therefore, the aforementioned education of talented design workers who are capable of integrating professional technologies is also a key to the technical advancement of Taiwan's manufacturing industry.

The annual reports of educational institutions show that various professional design techniques, and skills are offered at senior vocational schools and reinforced at the higher education level in technological institutes and universities. Statistical data reveals an increase of 16.7 fold in the demand for professional design specialists over a period of forty years[2]. As mentioned before, design will be one of the vital manpower requirements of the 21st century. Thus special investigations must be conducted in order to cope with future needs.

Chronologically, architecture design or engineering design programs were well established before industrial design education was first introduced in 1964 at Mingchih Institute of Technology. Since then many design programs have been systematically expanded in keeping with the socioeconomic development. Nowadays, design specialists in many areas are playing a vital role in the manpower structure and helping increase economic growth. Design education in Taiwan thus requires special attention and is worthy of study.

III. Updated Design Education: Results and Analyses

This study was conducted under the auspices of the National Science Council (NSC, Executive Yuan) over a period of three years. The study was divided into three phases: Planning, Experimentation and Evaluation, and focused on the topics of Course Models, Case Studies, Design Practice system,and Work Experience Studies. Four experimental projects integrated as an overall research program are described below. The first year, in the aforementioned four projects, design education was the main focus, and it was hoped to construct adaptive curriculum courses that correspond to the demands of the present socioeconomic environment of Taiwan and to establish a cooperative work program experience, as well as to open a design study center. Concurrently, a practicum or internship program was established so that the results of studies made by teachers and students could be published in periodicals or in the form of newsletters. This exchange of news will become a bridge to stir up more and better communication among designers, industrial personnel, and both domestic and overseas scholars. By literature surveys, questionnaires, visits and interviews, the opinions of domestic and foreign scholars and professionals were collected. The collected information was then compiled, analyzed and reduced to a model that fits the present socioeconomic environment.

The proposed model was assessed by experimentation as well as by evaluative meetings of scholars. The main conclusions are to (1) establish a proper system for selecting departments and curricula in order to retain students of suitable aptitude, (2) implement small group classes to gain the benefits of traditional apprenticeships as well as the advantages of a large class system, (3) conduct practicum at a design center so that all teachers and students get acquainted with business operations in the real world. The preliminary research results of this investigation are as follows.

1. Design Curriculum [4]

A questionnaire was prepared to find out what abilities industrial employers like to see their junior designers possess was sent to a total of 280 persons, including those active in industry and in academia. Information and opinions collected were analyzed and the eleven most important design abilities were ranked in sequential order as follows: innovative thinking, formative ability, design expression, analytical planning, fine arts, assessment ability, computer applications, design research, structural design, model construction, and production process flow charting. Except for design expression and model construction, statistical data showed that there were no significant differences in the demands made by the respondents. Based on this design ability analysis, this study suggested a selective curriculum system to group students by their own interests.

2. Case Study Teaching Method [5]

A total of 300 questionnaires addressing case study teaching methods and materials were sent out to collect relevant opinions. Statistical data revealed that the order of junior designers' abilities needing improvements are field experience, ability to organize and analyze, foreign language proficiency, and presentation and communication of ideas. The advantages of using case studies as a teaching method are many. One of the merits of case studies is that students can gain an early acquaintance with real world design practices. In addition, case study methods also make it easier for students to apply theories to actual business operations. Case study methods and materials can train students to tackle design problems and increase their ability to seek optimal design solutions. Effective techniques of teaching case studies have been summarized as three approaches, namely inviting experienced personnel to instruct the courses, holding seminars to acquire senior designers' guidance, and merging case studies into the overall curriculum plan. Preliminary data gathered from the designated group suggested that appropriate example cases can be best provided by design firms or the design departments of reputable organizations. Case materials can also be searched by students according to their interests, and example cases can be developed through governmental agencies or their subsidiaries.

Due to the domestic design environment, there are some limitations to acquiring cases. The willingness to provide case as teaching materials, the product categories, and the maturity of cases in relation to design courses are worthy of careful considerations when adopting this method.

3. Cooperative Work programs Between Education and Industry [6]

This study surveyed 233 subjects and reviewed literature related to cooperative work experience education. The terminology "cooperative work experience education" was first suggested in 1906 by Professor Hermon Schneider of University of Cincinnati. In Taiwan this terminology first appeared officially in the advisory committee regulations at vocational schools issued by the Ministry of Education in April 1936. In September 1974, the Ministry of Education published cooperative work experience guidelines to reinforce implementation. By this time the theory and legal bases were ready and vocational schools had started one after another to implement the cooperative work experience system. The results of this study showed that the necessity of establishing a cooperative work education system is supported by all sectors of society. While in academic institutions a special unit may exist to promote this system, other duties such as teaching and counselling students are always a high priority for teachers,making them too busy to attend to work-study affairs. Generally speaking, co-op system implementation is not satisfactory. Although there are industries eager to cooperate in work experience education, opportunities are limited.

From questionnaires returned and interviews held on two different occasions, the following results emerged. People in academic fields thought the willingness of industry to cooperate in work experience education is low. There is no unit or person in charge of the system in most schools. Transportation and the location of the cooperating firm form another problem. Budget shortages are the main reason prohibiting system implementation. However, 80 % of industry questionnaires indicated that they are in need of such cooperative work. Special project-type cooperation is generally welcome by industry especially utilizing summer sessions. Both parties recognize that design study centers within institutions will be the best partner for actualizing a cooperative education system.

4. Design Practicum System [7]

The themes of this study were (1) How to classify student ability in work practice to facilitate industry cooperation and (2) How to assess student attitudes toward practice. Results of questionnaires indicated that industry's general impression of student ability is "lacking maturity in design." Hence, it is obvious that schools have to have a correct way of evaluating students' talent so that industry has more confidence in them. As to the second question, questionnaires also indicated that students' willingness to learn is low (the fourth highest selection). Under normal circumstances, this is very surprising because students are encountering a completely new environment and should be excited about design work. Therefore, making the practicum environment more attractive to students is important to the success of practicum system. Off-campus practicums are mostly carried out during the long summer vacation. According to interviews with school personnel, difficulties occur due to shortages of fixed places and lack of adequate facilities for practice. Lack of reasonable compensation, boarding, insurance, welfare and safety are other barriers to be overcome. In addition, attitudes of employers towards students are not appropriate. Therefore, opportunities for students to bring their talent into full play are scarce. Problems in scheduling working hours and the length of the practicum constitute other aspects to be taken into consideration.

IV. Discussion

1. Curriculum Model

In order to broaden their career opportunities, elementary design courses are offered to freshman in design departments. In the second year students are counselled to select courses for future studies and may transfer to the department of their own choosing. In the third year, the students proceed with their studies in a particular field. For instance, the department of industrial design at this institute offers six different programs for students to choose from. In the final year the students may conclude their study by conducting a special design project lasting for nine months. In this way, a flexible and appropriate study curriculum plan can be established. In coordination with design center implementation, this model will fit the purposes of educating young designers and fully utilize available resources within institutions. Furthermore, it enhances opportunities for student participation in real design work, thereby increasing their professional ability .

2. Case Study Teaching Model

The results of this study were derived from a literature survey, questionnaires, and interviews and suggest two different case study teaching approaches that may be implemented for design students grouped in specialized areas. They are structural-type case study model and inductive-type case study model. The first model can provide actual cases or events for the analysis students using existing data on design problems and feasibility assessment. This model will enable students with limited experience to learn actual design practice in a framework of specific theories and ideas. The best time for implementation is in the third or fourth year. The inductive-type case study model makes students capable of digging into actual case examples to find problems. Usually this type of case study should include investigating potential problems, interviewing personnel of the company involved, collecting data, visiting the site,and seeking alternatives solutions for the problems. The student may perform feasibility analysis for the proposed alternatives. This model gives opportunities for students to participate in a project under real conditions, promote students' trouble-shooting ability and increases theoretical and practical knowledge.

3. Cooperative Work Programs Between Education and Industry

In summary, this study suggested the following three models that are practical and feasible for schools and industries. They are special project, holiday practicum, and one-year internship models. Special projects mainly offer every student designer a certain period of co-op works, while the holiday practicum meets educational objectives and the demands of industry. The one-year internship model allows student designers to gain professional experiences and broaden their design spectrum on a long-term basis.

4. Design Practicum System

In view of findings, this study established a practicum system for students in compliance with existing regulations, the demands of schools and industries and educational objectives. Feasible alternatives are to train and educate design personnel, recognize industry demand for design personnel, establish principles for a practicum system and draft plans for a practicum system. Overall, industry's demand for design work is the main source for offering student practicums. Design curriculum or courses may be set up in a way to provide for the needs of industry and orient students towards the actual needs. Student applicants shall fill in the work items, or submit their works for evaluation if they are qualified for the job or position offered by design office. The objective of training specialists and professionals is to develop designers' capabilities for the sake of industry and society. Design personnel demand surveys are essential to industry, and design courses should make fine adjustments to reflect needs. Besides students in their last school year who must take an off-campus practicum and participate in job orientation, undergraduate students are also encourage to participate in on-campus practicums and off-campus practicums during long vacations. Therefore, plans for a practicum system shall include students' off-campus practicum evaluation. It is planned to provide references for future employers and make assessment of abilities in professional practice. It is believed that the results of both on campus and off-campus practicums will directly enhance student designers' abilities in design. An effective way of incorporating these practicum ideas is to establish a design center to provide for outside design needs and to give students chances to practice design activities.

V. Summary and Conclusions

Education of professional designers is a key to success in upgrading technological levels of this nation's industry. Based on the preliminary results of this investigation, it is well recognized that institutes of technology or technological universities play significant roles in educating useful specialists for every sector of this nation. Besides educating students in a field of their own choosing to be a professionals, nurturing them in the area of the humanities and social sciences to be sophisticated individuals with highly developed ethics is also a mission in educating young designers from a wholistic point of view. The technological universities' contribution to the advancement of design, production and engineering technology of Taiwan to the international level should never be forgotten. Future development of design resources and manpower will inevitably rely on technological university education.

1. Establishment of A Design Center

An overall plan was devised after the research team studied and discussed the above models for curriculum, case studies , cooperative work experience, and student practice. During the process of study, two pannel discussions were held on these aspects with a total of 84 attendances of nationwide scholars and professionals. This study has suggested an unique model of educating design specialists and professionals for this country. The model includes an adaptive curriculum framework for students, adopts a divided case study approach, and suggests establishing a campus design center to offset the drawbacks of a cooperative work experience education system that never achieved satisfactory cooperation between industry and schools. The design center consolidates currently available resources and performs the functions of education, training, research, technical cooperation, and information services. It will also bring the distinguished features of this institution, especially in the four fields shown below into fuller play (Figure 1). Professional design education will be attained through the design center with the integration of currently available resources, curriculum selections, a case study teaching model, and cooperative work experience education. The center will also serve as a medium for developing mutually beneficial cooperation between industries and the institute in the areas of consulting, planning and carrying out design projects. In other words the center will become an effective channel for achieving design education extension work and applying theory to practices.

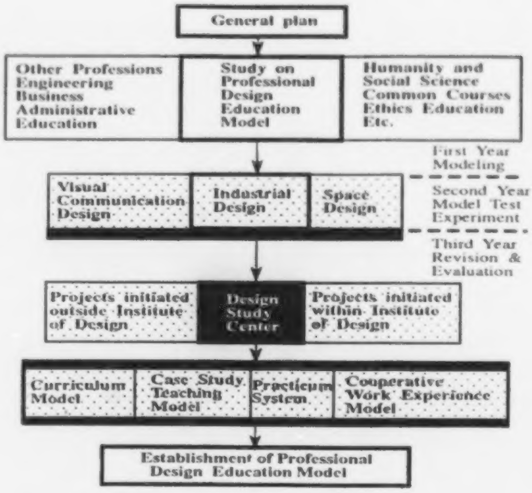
General plan
Other Professions Engineering Business Administrative Education
Study on Professional Design Education Model
Humanity and Social Science Common Courses Ethics Education Etc.
First Year Modeling
Visual Communication Design
Industrial Design
Space Design
Second Year Model Test Experiment
Third Year Revision & Evaluation
Projects initiated outside Institute of Design
Design Study Center
Projects initiated within Institute of Design
Curriculum Model
Case Study Teaching Model
Practicum System
Cooperative Work Experience Model
Establishment of Professional Design Education Model

Fig 1. Professional designers' education model for Taiwan.

In educating design professionals, other than the above mentioned tasks, there are still important factors that should be considered. Factors such as establishing a licensing system, standards for qualification of design professions, sources of students, recruiting of qualified teaching staff and their channels of promotion also require special attention.

In summary,the success of design education depends on the cooperation of three parties, namely industry, government and educational institutions. In addition, guidance given to students in selecting correct curriculum, positive action on teaching with small groups, improvement of the design practicum and cooperative work experience system coupled with design center to implement up-to-date ideas are all vital elements in enhancing students' professional abilities in design.

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References

Chian, W. S. (1993) Upgrading vocational education quality by reinforcing humanistic studies, *Journal of Technical and Vocational Education*, Vol 18, pp. 2-6.

Lin, J. C., Lee, T. L., Lin, I. C., (1991) A study of technical manpower educated in the institutes of technology in Taiwan, The Ergonomic Constitution Committee, manpower planning section, Administrative Yuan, Research report.

Chang, W. S., Lai, M. M. (1995) A study of an educational model for professional designers. NSC. Research report.

Ho, S. C., You, M. L. (1995) A study of an educational model for professional designers: Curriculum. NSC. Research report.

Sheu, F. H., Win, I. C. (1995) A study of an educational model for professional designers: Case study Model. NSC. Research report.

Chien, C. H., Young, C. C. (1995) A study of an educational model for professional designers: Co-op study. NSC. Research report.

Chen, S. H., Young, Y. F. (1995) A study of an educational model for professional designers: Practice System. NSC. Research report.

Yen, H. S. (1993) How to make our machine industry stable and vigorous, Lecture at the President's office for Dr. Sun, Y. S. Memorial Meeting.

設計教育模式

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摘　要

本研究吸取國內外設計敎育之長處，透過文獻探討與對產官學之問卷調查，綜合歸納出符合台灣現今社經環境之設計敎育模式，並透過敎學實驗，以及專家學者之座談，評估本模式之可行性。設計敎育模式實驗的要點在於(A)選系選學程的制度，獲取適性之學生，(B)分組式的敎育方式，兼顧師徒制及大班制的優點，(C)設計研習中心式實習，全體師生皆爲設計師，讓師生了解業界並能充分配合。

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OCTR: A Model of Learning Stages[1,2]

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ABSTRACT

This paper describes a model of learning stages called OCTR. Learning under OCTR advances gradually as the degree of social context increases. Furthermore, OCTR can also serve as a framework for describing the cognitive development and motivation of students, categorizing many existing teaching strategies, and better understanding how to introduce meta-cognition and attitude in systems for education.

Keywords: computer aided instruction, intelligent tutoring systems, cognition, meta-cognition, learning strategy, motivation, attitude, system design

I. Introduction

Our learning theories have affected the our design of computer systems for education, and the artifacts we make reflect our theories. For example, being influenced by behaviorism and realizing that the computer can provide an interactive learning environment, many educators adopted the stimulus-response approach in the development of early Computer Aided Instruction systems (CAI). Sometimes, our theories are implicit in our designs. For example, starting in the seventies, Intelligent Tutoring Systems (ITSs), which drew attention of many computer scientists and cognitive psychologists, have been basically modeled after the idea of private tutoring. This model promised to pay better attention to individual student needs (Bloom, 1984); therefore, a substantial amount of ITS research in the eighties was devoted to the study of student modelling. However, since the mid-eighties, the tutor-tutee model has been challenged.

Self and his colleagues first argued that the role played by the computer as an authorized teacher for transmitting certified knowledge should be de-emphasized. They suggested that the computer can be treated as a collaborator (or a co-learner) (Self 1985; Gilmore & Self, 1988; Cumming & Self, 1990; Dillenbourg & Self, 1992). Later on, as an alternative to the one-on-one model, Chan and Baskin (1988; 1990) proposed that the computer can be simulated as two coexisting agents, a teacher and a learning companion. The addition of the learning companion to the traditional ITS model yields collaboration as well as competition. More recently, an inverted ITS model which treats the computer as a student and the human learner as a teacher was suggested by Pathepu, Greer, and McCalla (1991). In summary, whether a collaborative system such as People Power (Dillenbourg & Self, 1992), a learning companion system (LCS) such as Integration-Kid (Chan, 1991), or a learning by teaching system, these approaches all suggest: (i) the computer should personify learning activities explicitly; in particular, one can model an *artificial*

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learner in a system (by simulation or machine learning); (ii) human students make cognitive gains by collaboration, competition, or teaching the *artificial* learner; and (iii) the computer can model multiple agents with different roles, like LCS, forming a small society in learning.

The latter concept seeks to recover the social context that has been lost in most computer-based learning environments. Despite the existence of an artificial learner in the system, this line of research coincides with the current interest in distance learning and computer supported collaborative learning via computer network. Moreover, the advancement of multimedia platforms has provided powerful devices for supporting complicated peer dialogue, gestures or facial expressions, and so on, and makes complex social learning systems more viable than before. But when we began to design a social learning system, LISA[3] (Learning IS Active), that intended to cover the whole repertoire of the student's learning process, we soon discovered that there are occasions when one-on-one tutoring is more effective. Thus, the need for a learning model of learning that incorporates both tutoring and social learning to facilitate system design becomes apparent.

Apprenticeship learning (Collins, Brown, & Newman, 1989; Collins 1991), which has influenced the design of many learning systems, resembles the skill acquisition process of an apprentice from a master. It consists of a set of teaching methods: (i) *modelcing*, where the student repeatedly observes how the teacher carries out a task; (ii) *scaffolding*, where the student is given a support to carry out a task and the support is gradually removed once the student is able to perform the task; (iii) *coaching*, where the teacher involves a whole range of activities: choosing tasks, modelling, providing hints and scaffolding, challenging and offering encouragement, etc.; (iv) *articulation*, where the teachers have a variety of methods for getting students to articulate their ideas and thinking process and; (v)*reflection*, where the student observes his own learning process and makes comparisons with others. While the master-apprentice model of learning does not seem to fit well into the paradigm of sociology of learning, the OCTR model introduced in this paper can be viewed as an extension of the apprenticeship learning model with a richer social context, mimicking the intensive knowledge communication nature of the modern society. Our study differs from other studies of learning, such as the three modes of learning by Rumelhart and Norman (1978), in its emphasis on learning stages and the articulation of a number of learning perspectives.

II. OCTR: A Staged Learning Model

The OCTR model views learning as a staged process. In these stages, learning objectives are defined and social context is incrementally embedded in the learning activities. The model is composed of four stages:

Orientation: in this first stage, the system helps the students relate their prior knowledge of the domain to be learned;

Coaching: this second stage is the same coaching activities as in apprenticeship learning;

Tuning: in this third stage, knowledge tuning is exercised via peer interactions and the teacher plays a less active role; and

Routinization: in this last stage, students solidify their knowledge by continuing to practice, perhaps under some forms of peer pressure.

In the rest of this section, we shall discuss how OCTR can serve as a framework for studying a number of aspects involved in learning; a summary of this is given in Table 1.

1. Cognitive Development

The foremost goal of OCTR is to try to describe the cognitive process of learning. There seldom exists a piece of completely isolated knowledge; or else it could hardly be learnt. As Piaget (1967) pointed out, a student is an active agent who seeks equilibrium between what he/she understands and what he/she experiences in the environment. Thus, in the orientation stage, the objective is to bridge what the student knows and what he/she shall learn by reviving the student's prior knowledge of the subject as it relates to the target task. The related old knowledge can be used as a theory for the student to interpret the new knowledge.

In the coaching stage, the system helps the student establish an initial mastery skill, and the

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[3] LISA is an inter-university project sponsored partially by the National Science Council. LISA intends to teach a set of small pedagogical languages for freshmen (Chan & Wang, 1991). The vision of the project is described in Chan (1993).

Table 1. Summary of OCTR

	Orientation	Coaching	Tuning	Routinization
Cognitive Devemopment	prior knowledge connection	knowledge growth	knowledge articulation	knowledge solidification.
Motivation	attention, curiosity, excitement	competence, moderate risk	sharing success, self-confidence	drive for survival, challenge, competence, external reward
Teaching Strategies	metaphors, story telling, etc.	modeling, scaffolding, fading	reflection, peer collaboration, retrospection, learning by teaching	assigning rank, compeition game, etc.
Meta-cognition	none	learning strategies, learning stages, meta-knowledge (strategic, control, heuristic), etc.	self knowledge (by teaching peers or self explanation)	self-knowledge (by monitoring peer working)
Attitude	goal, task, expectation, responsibiltity, etc.	enthusiasm, disposition, etc.	open, seek help & input from others, sharing success and failure, accepting making errors, etc.	effort

emphasis here is accretion of knowledge. Scaffolding and fading are essentially the system's control over the student's intellectual functioning: Fading is the cause of the student's internal disequilibrium and scaffolding is the support for reaching an equilibrium state. This process fosters cognitive development.

After the coaching stage, the student should have acquired some initial skill and reached a state of equilibrium again. Once the equilibrium state is reached, what will upset the equilibrium in order for the student to achieve higher levels of intellectual development? There are two ways: (i) By sequencing learning tasks with increasing complexity and diversity so that misconceptions or mistakes are revealed; and (ii) by placing the student in a social learning setting where "cognitive conflict" in the form of different ideas, views, and opinions emanating from peers will force the student to examine his/her thinking and look for alternative perspectives. The first way forces the student to apply what has been learned to multiple contexts. The second way provides an environment where meaning can be negotiated from multiple perspectives. In both ways, students modify their cognitive structure and the environment to their own ends, resulting in better articulated knowledge and a developing abstraction of acquired knowledge. This is the tuning stage.

Several points of social learning worth noting here. First, many details overlooked due to hastiness and first encounter in the coaching stage may be recovered in the tuning stage by shifting the most compelling elements in the stimulus from the coaching stage. This 'decentration' (Piaget, 1967) helps what used to be the secondary aspects be incorporated into the modified and more accurate total perception. Second, collaborative learning is a form of scaffolding since it is the distribution of thinking loading. The result of social interactions such as comparing, evaluating, justifying, and criticizing becomes part of the student's individual knowledge. Finally, peers' different perspectives on the subject can be considered as various versions of the student's own knowledge and are thus another form of reflection in apprenticeship learning. In short, as argued by Vygotsky (1978), the cognitive development process in such an environment is the gradual internalization and personalization of what was originally a social activity.

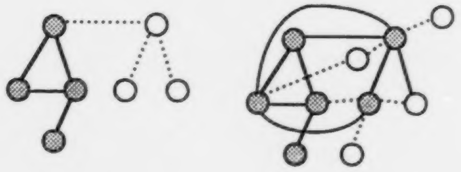
If tuning is aimed at making the target knowledge a robust part of the student's knowledge, then routinization or automatization through continuous practicing helps the student establish ownership and retention of that knowledge. Routinization empowers students by freeing their minds to be more attentive to other things (Collins, 1992).

2. Qualitative Explanation

We offer a simple qualitative model that explains cognitive development in the OCTR model. The model stems from constructism view (Bednar, et al., 1991; Jonassen, 1992), which holds that there is a real world that we experience. Learners create personal interpretations of the world based upon their past experiences and interactions with the world. Learning is a constructive process of building up an internal representation of knowledge. This representation is free to change constantly and its structure and linkages form the basis of new knowledge development and other knowledge attachment. The emphasis of constructism is on how we *construct* knowledge, rather than on studying the object of our knowledge.

First, we assume that knowledge consists of *units* and *links* (Figure 1). Units are pieces of knowledge and links connect these units. There are strong and weak units (represented by solid and hollow dots respectively) and links (represented by solid and dashed lines respectively). A strong unit represents a piece of fully fledged knowledge[4] and a strong link represents a strong relationship between two units of knowledge. Units can be created. If a unit has no link connected to it, then it can be regarded as deleted. Also, links can be created, deleted, strengthened, or weakened.

In the orientation stage, proper old knowledge is invoked to interpret newly created knowledge; that is, new but weak units are created with weak links connected to prior knowledge units in a similar structure of the prior knowledge. In the coaching stage, knowledge is expanded; that is, many weak units and links are created. Meanwhile, existing units and links are strengthened. In the tuning stage, knowledge restructuring is the main concern; that is, many links must be strengthened, weakened, and even deleted so that units created in the first two stages are better structured and more strongly related to prior knowledge. Finally, in the routinization stage, both units and links are strengthened to ensure their accessibility or usability in the future. Note that when multiple nodes and links are merged to form a strong node, we refer to this node-link model as a recursive model where abstraction can be described as the formation of strong nodes. Also, while we have not considered motivation in this qualitative model, we can regard it as a factor that affects the rate of acquiring knowledge in all of these stages.



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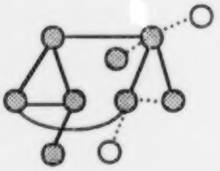

Articulation Solidification

Fig. 1. A qualitative representation of OCTR.

Viewing learning as different stages of constructing knowledge may play a role in interpreting situated learning (Brown, Burton, & DeKleer, 1988). Situated learning addresses domain-dependent learning in a rich context, practical knowledge, authentic activities in realistic settings, etc. In the first two stages of OCTR, situated learning addresses the help of knowledge construction to become 'anchored' (CTGV, 1990) at the proper 'site'. However, on the other hand, the last two stages of OCTR should provide domain dependent learning, abstract and theoretical knowledge by self-explanation or teaching by the learner, and allow decontextualization (Merril, 1991) by justifying knowledge via multiple perspectives given by peers and repetitive use of knowledge in multiple contexts, etc. It is this process that enables the student's knowledge to be 'transferable' from site to site. Contextualization and decontextualization applied at proper learning stages are both essential in preventing acquiring 'inert' knowledge — encapsulated knowledge that is rarely accessed or used again in the future (Whitehead, 1916).

3. Motivation

Motivation is a factor that determines

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[4] We can also regard a strong unit as a cluster of well connected units.

whether the students *will* do, not just whether they *can* do. The general goal of motivation is to design learning environments engaging enough so that the students are able to learn without feeling that they are making effort to learn, and students will learn even better if the system can trigger achievement-seeking behavior. In the orientation stage, the key to motivation is to draw the students' attention, promote their initial interest in the subject, and to revive them as curious, reaching-out, and experimenting individuals. Also, an atmosphere of readiness involving focusing attention and developing expectation can be acquired at this stage, like a prelude that helps the audiences prepare their minds to better enjoy a piece of music. To foster intrinsic motivation towards the subject in this stage, self-paced activities such as exploration or discovery games can be used, letting the students can actively produce effects on the environment (Woodworth, 1918). In addition, helping the students understand the importance and significance of the material and how it relates to real life may create a sense of excitement.

In coaching, the goal is to nurture the student's intrinsic motivation towards the subject. Intrinsic motivation, in the view of some researchers, is the need to encounter a moderate difference between the student's experience and his/her environment (Berlyne, 1978), while others (Woodworth, 1918) see it as the need to feel competent; that is, the ability to deal effectively with the surroundings. To this end, it is important to sustain a moderate risk in the learning task while still keeping it within the capacity of the student.

In the tuning stage, social learning protocols such as peer collaboration and discussion can be adopted. During collaboration, success in solving a problem is considered to be the success of each participating student and is thus a shared achievement. Also, collaboration contributes to students' self-confidence because it relieves insecurity when students see others struggle and realize that difficulties are not unique to them. Although it is still not clear what role motivation can play in social learning settings, the existence of a peer in learning may constantly stimulate a moderate difference which in turn arouses the student's innate need of competence (Chan, 1992).

In the routinization stage, learning tasks are not as challenging as before. Incentive is needed. Applying extrinsic motivation such as external rewards is one way. Another way is by means of competition that forces the students to evaluate their ability relative to their peers' in a social comparison process while at the same time provoking them to quest for survival — a phenomenon of the Darwinian "survival of the fittest." Higher competence information leads to higher intrinsic motivation while lower competence information results in lower intrinsic motivation. A recent informal evaluation of the Distributed West system shows that three times more students prefer learning under human competition to collaboration (Chan, et al., 1992; Chan, Chung, & Hue, 1992). This shows that competition is a powerful motivator. Finally, the relative perception of the student, which determines his/her motivational state, has to be modeled for guiding the system.

4. Quantitative Explanation

If knowledge can be constructed, then it must exist in some quantity that is measurable. For this reason, we propose a quantitative OCTR model that embodies both cognitive and motivational perspectives. *Learning load* (LL) defined by the formula below is a simple relationship of cognition and motivation. Although the formula is not ready to be actually measured operationally, it helps explain an individual's learning ability in the stages of coaching, tuning, and routinization.

$$\text{Learning Load} = \frac{(\Delta D - S)}{D \times M} + M_p$$

Here D stands for the background domain knowledge or experience, S for the scaffolding offered by the system, M for the motivation of the student, Mp for the peer pressure that is regarded as a part of motivation, and ΔD for the knowledge increment. Suppose that the maximum learning load that can be attained by an individual is a constant, then the overall objective of the system is, at any time, to maintain the detected LL as close to the student's maximum as possible, but not larger than the maximum (which means that the student cannot handle the task).

In all stages, we would like to keep the student highly motivated; that is, M is intended to be as large as possible. At the beginning, that is, during the orientation stage, we try to increase D by relating or activating as much as possible the student's prior experience. This strategy agrees with Kolodner's observation (Kolodner, 1983) that a domain expert learns faster than a novice does. Thus, one can learn more effectively if one has stronger experience. Note that, from the formula, if D and M are large, ΔD can be increased considerably. Thus, orientation seeks to enhance LL and prepare for the next three stages.

The purpose of coaching is to let students learn to tackle a complete task. However, according to Martin's law (Winston, 1992), one cannot learn anything unless one almost knows it already. This means that coaching has to be in small steps. However, if the steps are too small, we can hardly teach anything new. The problem is how to maintain ΔD, the knowledge increment, at a level where the student can learn without degenerating intrinsic motivation from the task. However, at the beginning of this stage, ΔD is too large for the student to handle a complete task alone; thus, an appropriate amount of scaffolding, S, should be exerted to reduce LL. Note that, modelling where S is very close to ΔD can be regarded as the extreme case of scaffolding. Also, fading begins as coaching proceeds, which means that S decreases.

Next, in the tuning stage, strengthening the integration of new knowledge with prior experience is the area of concern. There are two aspects here. First, peer collaboration (task sharing) can be regarded as a form of scaffolding, S, especially when the learning tasks are getting complex during this stage. Second, through peer discussion, ΔD in the form of cognitive conflicts is generated. This ΔD is a part of the personal domain knowledge D regarded as 'biased' in the social community (Sack, Soloway, & Weingrad, 1993). Through reconciliation, ΔD vanishes and is absorbed into D, and the process repeats when other issues arise. Note that, ΔD is no longer as large as during the coaching stage; yet, each student has to think and contribute a piece of the discourse. This mutual responsibility and expectation yields a certain amount of peer pressure. That is, when the first term of LL lessens, the second term, M_p, emerges.

In the routinization stage where the emphasis is to solidify the learned knowledge, both ΔD and S have declined; that is, the first term of LL vanishes. To maintain the momentum of learning, M_p, emanates to become a dominant term. In other words, students are engaged in a competitive environment where their innate instinct for survival drives them to face the challenge.

5. Teaching Strategies

The stages of OCTR bring together most useful teaching strategies, and place them in a learning repertoire with increasing social elements. It begins with teacher-controlled description or self-paced exploratory learning, and advances to one-on-one coaching, and then to complex social learning settings.

For orientation, we may carefully choose examples in real life or use metaphors to bridge the gap between a new concept and prior knowledge. Similarly, we can organize the material in a story form to invoke the students' experience and enable them to preliminarily grasp the concept with an analogical model. Perhaps the most preferred way in this stage is discovery learning in which students explore and gain experience on their own through a simulation game or microworld.

As for coaching, it personalizes the interaction first by modelling, then by scaffolding and fading alternatively. In a computer-based learning environment, scaffolding can be in the form of specially designed devices, depending on the particular material to be learned or the help or hints offered by the system.

Reflection, a part of apprenticeship learning, is a form of tuning by replaying and reviewing the student's learning process and achievements. Another form of tuning is through social interaction where social context can be structured by various protocols with a broad spectrum of possible variations on the number and identities of the agents (Chan & Baskin, 1990). Each of these variations gives rise to particular cognitive issues in the student's learning. Finally, retrospection, rather than reflection, should also be instituted in this stage in the form of abstract reformulation of what has learned.

Apart from external rewards, a method for routinization is to design a problem solving game in which the acquired knowledge is a part of the means to solve the problem, such as the classical West program (Burton & Brown, 1979). We may also assign a rank to the student's ability or use a score board to record the achievements of different students as an explicit way for the student to compare himself or herself with others. An intensive competitive method is to apply real time social pressure in a distributed learning environment such as the Distributed West system (Chan, et al., 1992). In such environments, group-to-group is preferable to one-to-one since success and failure can be shared, instead of having an individual take full responsibility.

6. Meta-Cognition

Due to the rapid progress of new technologies, what we learn today will inevitably become obsolete someday in the future. Learning "how to learn" in preparing for future job training is thus becoming more important than ever. Within the framework of OCTR, meta- and self-knowledge can be learned in the last three stages. In the coaching stage, meta-knowledge such as strategic, control, and heuristic knowledge can be made explicit by the coach in modelling. Learning strategies such as those discussed above and learning stages of OCTR can all be introduced by the coach as part of the student's learning experience. Learning self-knowledge seems to be best realized in the tuning stage where the student can see how peers deal with the same problem and compare different ways of doing things. This allows the students to develop new ways of seeing and talking about what they do (Collins, 1992). An interesting protocol at tuning is reciprocal teaching (Palincsar & Brown, 1984) where an implicit cognitive task is partitioned into several explicit sub-tasks performed by different students who take turns undertaking each of these sub-tasks. This is an effective form of peer discussion protocol. Learning by teaching to encourage self explanation can be utilized at this stage too. Finally, for routinization, the Sophie game protocol (Brown, Burton, & DeKleer, 1982) may be adopted where one student is working on one computer while his/her activity is monitored by another student, probably via another computer.

7. Attitude

There is an old Chinese adage stating that the Five Educational Objectives are *Ethics, Knowledge, Athletics, Sociability*, and *Art*. Among them, knowledge has become so important that schools merely function as factories to produce massive numbers of graduates equipped with necessary knowledge to meet the demands of society. One characteristic of the apprenticeship learning used in the old days was that the student could learn things like personality, temperament, disciplines, etc., directly from his/her master. A mission of future intelligent learning systems is perhaps to embody ethics, sociability, attitude, etc. However, this mission would be controversial because these elements are beyond our domain knowledge. This is analogous to the well-known debate a thousand years ago in China during the Tang Dynasty on whether literary work was for the sake of morals or just for literature itself. It is also potentially difficult to implement such as scheme, for it is not easy to identify what is right or wrong in ethics and sociability, etc.; since these elements are on the brim, they can only be touched at opportune moments while learning the domain knowledge.

In the orientation stage, the system helps the student set up goals and expectations, so that learning becomes a clearly defined task to achieve an aim. In the coaching stage, the coach is talking around the student and may encourage the student to try more difficult problems without being afraid of failing. Besides, the coach's valuable learning experience, enthusiasm, vigour, etc., can also be passed on to the students. In the tuning stage, collaboration helps the student develop an attitude that is more open and willing to seek out help and input from others, and also helps the student learn to share success and failure with others. In addition, by observing peers at work, the student will learn that making errors is a natural phenomenon in learning. In the last stage, routinization, some students may be inhibited or discouraged rather than motivated by competitive situations if they believe that making errors makes them 'dumb' (Collins, Brown, & Newman, 1989). Thus, the value of effort, not ability or results, should be emphasized (Anderson, 1992). Society is indeed filled with competition and collaboration, and students have to learn to face them.

Students' attitude is the outcome of their internal beliefs. Apart from the didactic instruction discussed above, it is important to represent and detect students' wrong beliefs (such as making mistakes makes one dumb) in the system.

III. System Design with OCTR

There is a firm link between a learning model and the prescriptions for practical system design. We show this by highlighting the OCTR-Tree architecture that we are building for the ISA project. OCTR adopts the assumptions of

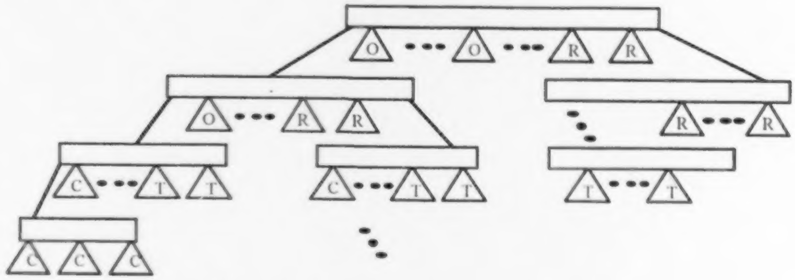

Fig. 2. OCTR-tree architecture.

Curriculum-Tree knowledge-based architecture (Chan, 1992) where the domain knowledge structure is isomorphic to the learning goal hierarchy.

In this curriculum hierarchy, each node can possess a cluster of episodes. An episode is a small unit of learning activity, usually having a beginning and an end. Based on different stages of the OCTR model, these episodes are classified into O, C, T, and R. There is no strict distinction among different stages of OCTR and the distribution of the episodes in the tree is iteratively spiral (Figure 2).

IV. Discussion

We have shown that OCTR is a common thread of more specific learning theories such as motivational considerations, situated learning, and social learning, and it makes them easier to present, analyze, and contrast. In addition, OCTR can be used to compare some phenomena. For example, from the functional point of view, traditional CAI systems seem to focus on orientation and routinization, and ITS research concentrates more on coaching. This is the case for ITS' partly because there are more intriguing AI issues, such as student modelling in the coaching stage than in the orientation and routinization stages. Social learning, on the other hand, may contribute to tuning and routinization. Thus, if all stages are equivalently significant in learning, then OCTR unifies the different addresses of these communities.

OCTR can also serve as a framework to compare different educational practices in the East and the West. In the competitive educational systems developed in some Asian countries, where survival in public examinations is the main objective of almost all students, the emphasis is mainly on modelling (the first part of coaching) and routinization, leaving other parts of coaching and tuning unattained. However, many Asian families employ private tutors for their children. In the West, orientation and tuning seem to be key parts of the classroom teaching. While orientation and tuning encourage independent thinking and innovative ideas, inadequate emphasis on routinization will result in the decline of the students' performance in examinations. This difference in educational philosophies partly reflects the cultural difference between the West and the East.

It is interesting to note that no system known has ever paid equivalent attention to all four stages of OCTR. The generative learning illustrated in the Jasper series (CTGV, 1990), for example, emphasizes on the orientation stage of OCTR. It is a sequence of videodisc based adventures designed to motivate students to think and reason about complex, real life problems. These problems are embedded in the contexts of the adventure stories presented in the videodisc. 'Anchored' in these contexts, students' curiosity is aroused and they search data from the story, analyze data, and solve problems, usually with the help of a human teacher. Thus, while the contexts of the adventures effectively supports the orientation stage, the coaching stage requires human teachers. However, a recently developed intelligent tutoring system, Adventure Player (Crews, Biswas, & Bransford, 1995), supplements this need at the coaching stage when students solve the Jasper problems. Nevertheless, Jasper's experiments do not touch much about the tuning and the orientation stages. KIE (Bell, Davis, & Linn, 1995), a learning environment on Internet, on the other hand, stresses on the tuning stage. It provides a set of tools to help students access information and receive social supports in discussing complex scientific ideas. In fact, on Internet, it is possible to develop various kinds of features to facilitate the development of all four stages of OCTR. This is because any feature that standalone systems provide can also be transferred to the Internet, in addition to the social learning experience that might be obtained through Internet (Chan & Chou, in press; Chan, in press).

There seems to have two ways to embed intelligence in a system for education. One is to facilitate system designers to build systems that can take into account our learning theories in a general architecture, such as the OCTR-Tree. The other is to ensure individualization by student modelling. Constructivism considers learning a construction process of personal interpretation of the world. This implies that the content of a cognitive structure is unique to an individual student; hence this assumes infinite variations and, therefore, does not favor strong student modelling unless experience of all students can be modelled or constrained. However, we feel that there is at least a need of weak student modelling to detect and bring individual students' 'biased' knowledge back to within the boundary accepted by the larger community. Furthermore, the horizon of student modelling research should be broadened: student modelling = cognition + motivation + meta-cognition + attitude, like our discussion of the OCTR model above. For motivation, there have been some initial attempts (Soldato, 1992); for social learning, even though there are a number of prototypes, many problems remain; for meta-cognition, some discussion can be found in the literature, but few systems have been implemented; and for attitude, not much discussion is even available in literature. Therefore, this extended notion of student modeling is undoubtedly more challenging.

Perhaps, from the system design's point of view, the most important contribution of OCTR is that it offers *learning completeness.* By this we mean that a model of learning that subsumes all the learning sub-processes of the student; and shows how learning is taking place with clear and objective indications, both microscopically and macroscopically. Moreover, this learning completeness underlies *learning soundness.* By this we mean during the design process, the model facilitates identification of goals and justification of teaching strategies in developing an approach toward the goals. Of course, whether the OCTR model can accurately and sufficiently describe the stages of human learning and be a 'useful' framework for designing effective learning environments remain to be tested. Nevertheless, we feel that there is a pressing need for this direction of research, and we hope that our work will initiate more study in this direction in the future.

References

Anderson, J. R. (1992). Intelligent tutoring and high school mathematics. *The Proceedings of 2nd International Conference of Intelligent Tutoring Systems* , Lecture Notes in Computer Science, Springer-Verlag.

Bednar, A. K., Cunningham, D., Duffy, T. M., & Perry, J. D. (1991). Theory into practice: How do we link? In G. Anglin (Ed.), Instructional Technology: Past, Present, and Future, Denver, CO: Libraries Unlimited.

Bell, P., Davis, E., & Linn, M. (1995). The Knowledge Integration Environment: Theory and Design, *The first International Conference on Computer Support for Collaborative Learning*, Indiana, USA, 14-21.

Berlyne, D. E. (1978). Curiosity and learning. *Motivation and Emotion*, Vol. 2, 97-175.

Bloom, B. S. (1984). The 2 sigma problem: the search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, Vol. 13, 4-16.

Brown, J. S., Burton, R. R., & DeKleer, J. (1982). Pedagogical, natural language and knowledge engineering techniques in SOPHIE I, II, and III. In D. Sleeman & J. S. Brown (Eds.), *Intelligent Tutoring Systems, New York*: Academic Press, 227-282.

Brown, J. S., Collins, A., & Duguid, P. (1988). Situated cognition and the culture of learning. *Educational Researcher*, **18**(1), 32-42.

Burton, R. & Brown, J. S. (1979). An investigation of computer coaching for informal learning activities. *International Journal of Man-Machine Studies* , Vol. 11, 5-24.

Chan, T. W. (1991). Integration-Kid: a learning companion system. *The Proceedings 12th International Joint Conference on Artificial Intelligence* , Sydney, Australia, Morgan Kaufmann Publishers, Inc., 1094-1099.

Chan, T. W. (1992). Curriculum tree: a knowledge-based architecture for intelligent tutoring systems. *The Proceedings of 2nd International Conference of Intelligent Tutoring Systems*, Lecture Notes in Computer Science, Springer-Verlag, 140-147.

Chan, T.W. (in press) Learning Companion Systems, Social Learning System, and Global Social Learning Club. Invited Talk, World Conference on Artificial Intelligence in Education, Washington, DC, USA, *Journal of Artificial Intelligence in Educaion* , to appear.

Chan, T. W. & Baskin, A. B. (1988). Studying with the Prince: the computer as a learning companion. *Proceedings of International Conference of Intelligent Tutoring Systems*, June, Montreal, Canada, 194-200.

Chan, T. W. & Baskin, A. B. (1990). Learning companion systems. In C. Frasson & G. Gauthier (Eds.) *Intelligent Tutoring Systems: At the Crossroads of Artificial Intelligence and Education*, Chapter 1, New Jersey: Ablex Publishing Corporation, 6-33.

Chan, T.W. & Chou, C.Y. (in press). Exploring the Design of Computer Supports for Reciprocal Tutoring. *Journal of Artifical Intelligence in Education*, to appear.

Chan, T. W., Chung, Y. L., Ho, R. G., Hou, W. J. & Lin, G. L. (1992). Distributed learning companion systems — WEST revisited. *The 2nd International Conference of Intelligent Tutoring Systems*, Lecture Notes in Computer Science, Springer-Verlag, 650-643.

Chan, T. W., Chung, Y. L. & Hue, C. W. (1992). Evaluation of distributed learning companion system. *Proceedings of East-West Conference on Emerging Computer Technologies in Education*, Moscow, 56- 59.

Chan, T. W. & Wang W. C. (1992). Problem-solving model approach for teaching multiple introductory programming languages. *Proceedings of East-West Conference on Emerging Computer Technologies in Education*, Moscow, 51-56.

Cognition and Technology Group at Vanderbilt (1990). Anchored instruction and its relationship to situated cognition, *Educational Researcher*, **19**(3), 2-10.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: teaching the craft of reading, writing and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser*, Hillsdale, NJ: Lawrence Erlbaum Associates Publishers 121-138.

Collins, A. (1992). Design issues for learning environments. In S. Vosniadou (Ed.) *Psychology and Educational Foundations of Technology-Based Education*, New York, Springer Verlag.

Crews T., Biswas, G. & Bransford, J. (1995). AdventurePlayer: macrocontext plus microworlds. *The proceedings of 7th World Conference on Artificial Intelligence in Education*, Washington, DC, USA, AACE, 381-388.

Cumming, G. & Self, J. (1990). Collaborative intelligent educational systems. In D. Bierman, J. Breuker, & J. Sandberg (Eds.), *Artificial Intelligence and Education*, Amsterdam: IOS, 73-80.

Dillenbourg, P & Self, J. (1992). People Power: a human-computer collaborative learning system. *The Proceedings of 2nd International Conference of Intelligent Tutoring Systems*, Lecture Notes in Computer Science, Springer-Verlag, 651-660.

Gilmore, D. & Self, J. (1989). The application of machine learning to intelligent tutoring systems. In Self, J. (Ed.) *Artificial Intelligence and Human Learning, Intelligent Computer-Assisted Instruction*, New York: Chapman and Hall, 179-196.

Jonassen, D. H. (1992). Objectivism vs. constructism: do we need a new philosophical paradigm? *Educational Technology: Research and Development*. Vol. 39, No. 3, 1992, 5-14.

Kolodner, J. L. (1983). Maintaining organization in a dynamic long-term memory. *Cognitive Science*, **7**, 243-280.

Merril, M. D. (1991). Constructism and instructional design, *Educational Technology*, May 1991, **31**(5), 45-53.

Palincsar, A. S. & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction*, **1**, 117-175.

Palthepu, S., Greer, J., & McCalla, G. (1991). Learning by teaching. *The Proceedings of the International Conference on the Learning Sciences*, AACE, 357-363.

Parkes, A. P. & Self, J. A. (1988). Video-based intelligent tutoring of procedural skills. *International Conference of Intelligent Tutoring Systems*, June, Montreal, Canada, 454-461.

Piaget, J. (1967). *Biology and Knowledge*. Paris: Gallimard.

Rumelhart, D. E., & Norman, D. A. (1978). Accretion, tuning, and restructuring: three modes of learning, In J. W. Cotton & R. L. Klatzky (Eds.), *Semantic Factors in Cognition, Hillsdale, NY: Lawrence Erlbaum Associates*, 37-53.

Sack, W., Soloway, E., & Weingrad, P. (1993). Re: Writing Cartesian student models. *Journal of Artificial Intelligence in Education*, Vol. 3, No. 4., 381-400.

Soldato, T. D. (1992). Detecting and reaction to the learner's motivational state. *The 2nd International Conference of Intelligent Tutoring Systems*, Lecture Notes in Computer Science, Springer-Verlag, 567-574.

Self, J. A perspective on intelligent computer-assisted learning. *Journal of Computer Assisted Learning*, Vol. 1, 159-166.

Whitehead, A. N. (1916). *Address to the British Mathematical Society*. Manchester, England.

Winston, P. H. (1992). *Artificial Intelligence*, 3rd Edition. Addison Wesley.

Woodworth, R. S. (1918). *Dynamic Psychology*. New York: Columbia University Press.

OCTR: A Model of Learning Stages

OCTR：一個學習階段的模型

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摘　要

此論文描述一個稱爲OCTR的學習階段模型，在此模型下，學習過程中不同階段的社會內涵會逐漸增加。此外，OCTR並可作爲一個架構，用在電腦輔助學習系統上來描述學生的認知發展及動機，並可以把教學策略分類，以及增強了解如何引入後設認知及學生的學習態度。

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On Defining the Similarity of Navigation Patterns in a Hypertext Tutoring System - A Quantitative Approach†

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ABSTRACT

We propose a quantitative approach to determining the similarity of navigation patterns in a hypertext system. The motivation of this work is to define the similarity between the learning patterns of students when they use a hypertext tutoring system. The longest common subsequence and the differences of many other attributes are mapped to real numbers to represent the similarity. We show that if the hypertext system can be represented as an acyclic digraph, the longest common subsequence can be obtained efficiently. For the general case that the digraph is not acyclic, we propose to use metrics to define the similarity. Metrics based on the longest common subsequence and other attributes are presented. Students' learning patterns can be analyzed by further application of clustering methods.

Keywords: Hypertext, tutoring system, directed graph (digraph), navigation patterns, longest common subsequence, metric.

I. Introduction

Hypertext is a system of storing, accessing, and presenting information. Used when "text" alone is not sufficient for such operations, hypertext combined with other multimedia elements is called "hypermedia", and has grown to include many different media forms, such as images, graphics, sound, and animation. In this paper, we use *hypertext* to mean all *hypermedia*.

Hypertext systems are being used in many applications because of their flexible structure and the browsing freedom they provide. Recently, hypertext systems for the education community have become technologically feasible. The ability to store, manage, and retrieve large amounts of information rapidly, coupled with the capacity for images and sound, has revolutionized teaching and learning approaches. Many systems like the Renaissance Information Management System (RIMS) [12], and the Perseus Project [8] have been built.

A complete tutoring system should offer more than hypertext. Consider two features that might be included in a tutoring system:

- It might help students who encounter problems by using knowledge from previous or parallel cases to "instruct" them in the methods others have used to overcome similar problem.

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- Hypertext systems run on networks could help frustrated students by connecting them with others on a similar learning track; the students could then discuss their difficulties and cooperate in helping each other learn.

Both proposals require that the tutorial system have knowledge of previous use patterns, leading us to conclude that there is a need to design a representation of how users navigate through tutoring systems, and to define similarities among navigation patterns.

In this paper, we consider the problem of defining the similarities among student navigation patterns, and propose a quantitative approach. The proposed quantitative approach can accomplish the above requirements. Furthermore, the calculated quantities provide ways to characterize learning patterns of students, which is important in analyzing the learning behavior of the students. The quantity we design is based on the "longest common subsequence" and the metrics.

A hypertext system is generally a directed graph (a digraph). If it is not directed, we can always transform the graph into a digraph by replacing an edge with two parallel directed edges with opposite directions. The navigation pattern thus becomes a directed path in the digraph. Since each node can be labeled as a symbol, the directed path can be represented as a string. The similarity between two navigation patterns is thus reduced to the similarity between two strings. The *longest common subsequence* (LCS) between two strings can then be applied to evaluate the similarity.

The LCS between two strings is generally solved by dynamic programming [4] which takes $\Theta(mn)$ time where m and n are the lengths of two strings. If one must find the longest common subsequence of two strings A and B by using dynamic programming, we can expect high computing costs for long strings A and B. In this paper, we show that if the digraph representing the hypertext is acyclic, then the navigation patterns can be stored as 0/1-bit strings, and matching two patterns can be carried out very efficiently by the Boolean AND operation. The acyclic digraph is not really a bad assumption for a tutoring system since nodes in such systems generally own precedence relations. For example, it does not make sense to say one should start a course after he or she has finished the course. This means the relationships between nodes is irreflexive and thus the graph should be acyclic.

However, the acyclic assumption becomes untrue if there are operations such as "Cross Reference" or "home". That means we still have to face the problem of dealing with a general digraph. To solve this problem, we propose to define the "distance" between two navigation patterns, i.e., the metric. In this paper, we design metrics based on the LCS and other attributes. Based on these metrics, the similarity between pairs of navigation patterns can be solved by an algorithm such as in [11]. Furthermore, to characterize the learning behavior of students, the clustering analysis [1] can also be applied.

This paper is organized as follows. We first briefly state the representation of the navigation patterns and the longest common subsequence in Section 2. In Section 3, we discuss the case where the digraph representing the hypertext is acyclic. An efficient algorithm to determine the LCS is presneted. We also report on a simple experiment to evaluate the performance of our algorithm against dynamic programming. If the digraph is cyclic, we propose solving the matching problem using metrics. Metrics based on many attributes are defined in Section 4. The final section presents conclusions and discussions.

II. Preliminaries

1. Path representation

A hypertext system is usually defined as a set of nodes that contain information, and a set of link s that connect interrelated nodes [2, 3]. In general, since the links are directed, we can use directed graphs (digraphs) to represent hypertext systems. The navigation patterns generated by browsing through text can thus be represented by the sequence of vertices traversed in the digraph. Let $G=(V, E)$ be an digraph and $|V|=N$. We can denote each node in v a symbol. For example, we can index the nodes with integers from 0 to $N-1$. The navigation patterns then become a set of strings over the set of symbols $\{0, ..., N-1\}$.

2. The LCS

The longest common subsequence (LCS) is defined as follows. A subsequence of a given string is any string obtained by deleting zero or more symbols from that string. A longest common subsequence of two strings is a subsequence of both that is as long as any other common subsequence. For example, "B, C, B, A" and "B, D, A, B" are the longest common subsequences of "A, B, C, B, D, A, B" and "B, D, C, A, B, A". The LCS is often used to represent the similarity between two sequences. For example, in data processing LCS is used measure the differences between two files, and in molecular biology LCS is used to gain information about new protein sequences. Similarly, the LCS can be applied to evaluate the similarity between two hypertext navigation patterns. The longer the LCS is, the more similar the two navigation patterns are. The LCS of two strings of length m and n is generally obtained by dynamic programming, which takes $\Theta(mn)$ time.

III. Matching Navigation Patterns in Acyclic Systems

The LCS between pairs of navigation patterns is obtained by dynamic programming. Since the computing time for dynamic programming is $\Theta(mn)$, which grows quadratically, matching pairs of long navigation patterns could take a very long time for large m and n. Fortunately, there is an efficient algorithm for computing the LCS if the navigation patterns are obtained from an acyclic digraph. In this section, we show that if the digraph is acyclic, the navigation patterns can be represented by 0/1-bit strings. Furthermore, the LCS of two patterns can be obtained by Boolean AND operations rather than dynamic programming.

1. Representation of the Navigation Patterns in an Acyclic Digraph

Let G=(V, E) be an acyclic digraph representing hypertext. There must be only one vertex v in G such that v has indegree 0. Any other v′ with zero indegree can never be reached. Also note that, since the digraph is acyclic, the relation over the set of vertices defined by the directed edges is irreflexiue. That is, the topological sort gives a total order of vertices in V and the total order will not violate any partial order defined by the edges [6]. Furthermore, the vertex with zero degree must be the first vertex in the total order if we re-index the vertices in G by the ordering produced by the topological sort. The vertex with zero indegree thus has index 0 denoted v_0. Any directed path that starts with v_0 and ends up with a vertex v_i has the monotone property stated in the following theorem.

Theorem 1. Let G=(V, E) be an acyclic digraph and the vertices be indexed as the result of topological sort. If $p=v_0, \ldots, v_i$ is a path in G, then the indices of vertices on p are strictly increasing.

Proof. Consider a directed path $u_0, u_1, u_2, \ldots, u_k = v_i$, in G. u_j and u_{j+1} on the path imply that there is a directed edge $<u_j, u_{i+1}>$ in E. Since G is acyclic, the topological sort will output the vertex u_i before the vertex u_{i+1}. Thus the index of u_i must be smaller than the index of u_{i+1} in the ordered list.

Since indices of the nodes on each path must strictly increase, a learning path can be stored in an array of length n where N=|V|. Entry i in the array is 1 if v_i has been visited and is 0 otherwise. The navigation pattern is then a 0/1-bit string.

Matching two paths can be done by simply taking the Boolean AND operation of the bit strings representing the two paths. The number of 1's in the resulted bit-string is the length of the longest common subsequence.

2. Experiment

In order to evaluate the performance of our proposed algorithm against dynamic programming, we conducted a simple experiment. We first constructed an acyclic digraph and then extracted 1,000 navigation patterns from the digraph. The run time statistics for dynamic programming and our approach were obtained from matching 20 patterns of the 1,000 patterns.

2.1 Graph Generation

The generated digraph should have a source node from which all the other nodes can be reached. We generated the digraph by first constructing a spanning tree connecting all the vertices. We then added edges to the digraph while maintaining its acyclic property. The algorithm for digraph generation is as follows. Suppose there are |V|=N nodes labeled from 0 to N-1. The node labeled i is denoted by v_i. v_0 is the source of the generated digraph.

①Tree construction: For each node v_i, i=1 ... N in V, we randomly chose a node with a label smaller than i, and added an edge directly from the chosen node to v_i.

②For the other edges: To add the other edges we randomly chose two nodes v_i and v_j, $0 \le i, j \le N$. Assuming that $i<j$, we added a directed edge from v_i to v_j.

The generated digraph was acyclic since all the edges directed from a node with a smaller label to another node with a larger label. We then proved by induction that we could reach any node v_i, $i>0$ from v_0. Clearly, v_0 can reach v_1. Suppose v_0 can reach v_j, $1 \le j \le i$. For the node $i+1$, there must be a link from v_k to $v_{(i+1)}$ for some k, $1 \le k \le i$. Hence v_0 can reach $v_{(i+1)}$ through the directed path from v_0 to v_k then following the directed edge $<v_k, v_{(i+1)}>$.

2.2 Results

The navigation patterns were generated by randomly traversing the digraph. The run time statistics for our approach and dynamic programming are shown in Tables 1. The run times shown are for finding the closest path out of 1,000 paths for 20 given paths. The number of nodes in each digraph is shown in the first column, and the first row represents the ratio of the number of edges to the number of nodes, i.e., the average indegree of nodes. In all cases, our method is much faster than the dynamic programming.

Table 1. Comparison of the Run Time for Our Method Against Dynamic Programming. The Computing Time Required for Our Method is Shown in Bold. If There are 800 Nodes in The Graph, and The Number of Edges is 4,800 (800 times 6), the Computing Times for Our Method and Dynamic Programming are Shown at the Entry (800,6). That is, We Needed 1.57 Seconds to Find the Closest Path Out of 1,000 Paths for a Given 20 Paths while Dynamic Programming Took 38.71 Seconds.

	4	5	6	7	8
500	1.01 39.78	1.03 39.71	1.01 39.55	1.02 37.46	1.01 39.30
600	1.19 36.64	1.19 39.19	1.18 36.12	1.18 37.18	1.20 39.50
700	1.41 40.06	1.39 37.81	1.37 37.33	1.39 37.81	1.38 38.01
800	1.57 37.11	1.56 38.38	1.57 38.71	1.55 39.86	1.55 38.58
900	1.90 39.27	1.86 38.12	1.86 39.63	1.91 41.59	1.87 39.12
1000	2.08 38.26	2.08 38.91	2.08 39.57	2.14 40.18	2.08 38.24

IV. Matching Navigation patterns in General Digraphs

The proposed solution in Section 3 is based on the assumption that the digraph representing the hypertext is acyclic. As mentioned above, there is a chance that the digraph is not acyclic. For example, there may be cross references, or students may have to go back to read some material before (re-visiting previously visited node). All these actions prevent the monotone property of the indices of nodes on the navigation patterns from holding. Accordingly, we propose defining the metric, he distance functions between pairs of paths. Several advantages can be gained by using the metric. If the metric is defined, the problem becomes a proximity problem or a clustering problem [1, 10]. Secondly, we are able to combine several attributes together since adding metrics yield another metric.

In the remained of this section, we first give some definitions. We then design a metric based on the LCS. Since metrics defined by only one attribute may not be able to precisely describe the similarity between two navigation patterns, we thus define metrics for other attributes. Finally, we propose some composite metrics.

1. Metrics

Let S be the set of navigation patterns obtained from a hypertext system. Recall that we can use integers to index the vertices. Thus S is a set of strings over non-negative integers and the empty string.

Definition 1. Let x, y, and z be in S. A function f(x, y) is said to be a metric, if

$$f: x \times y \Rightarrow R, \forall x, y, z \in S$$

such that

1. $f(x, x)=0$,
2. $f(x, y)>0$,
3. $f(x, y)=f(y, x)$,
4. $f(x, y)+ff(y, z)>f(x, z)$.

By this definition, we shall look for distance functions between two navigation patterns such that:

- The distance between two identical paths is 0.
- For two paths $A \neq B$, the distance between A and B is greater than 0.
- The distance from a to B is equal to the distance from B to A.
- The distance function meets the triangle inequality.

2. LCS Metric

As mentioned above, the LCS can be used to evaluate the similarity between navigation patterns. In fact we can define a metric, D_{lcs}, based on the LCS. If there are a pair of navigation patterns having small distance of D_{lcs}, this pair of navigation patterns are considered similar. The D_{lcs} is defined as below.

Definition 2. Given two navigation patterns $A=a_1, \ldots, a_m$, and $B=b_1, \ldots, b_n$ in S, the distance function, denoted D_{lcs}, is defined as:

$$D_{lcs}(A, B)=m+n-2|LCS(A, B)|$$

where $|LCS(A, B)|$ is the length of the LCS(A, B).

Observe that if two learning paths A and b have a long longest common subsequence, then we expect they will have a small $D_{lcs}(A, B)$. We now show that the distance function is a metric.

Lemma 1. The distance function D_{lcs} is a metric.

Proof: let $A=a_1, \ldots, a_m$, $B=b_1, \ldots, b_n$, and $C=c_1, \ldots, c_l$, be three navigation patterns in S. It is obvious that $D_{lcs}(x, x)=0$, $D_{lcs}(x, y)\leq 0$, and $D_{lcs}(x, y)=D_{lcs}(y, x)$, where $x, y \in \{A, B, C\}$.

We now show the function meets the triangle inequality. We argue the case that:

$$D_{lcs}(A, B)+D_{lcs}(A, C)\geq 0,$$

and the other cases are symmetric.

$$D_{lcs}(A, B)+D_{lcs}(B, C)-D_{lcs}(A, C)$$

$$=m+n-2|LCS(A, B)|+n+l-2|LCS(B, C)|$$

$$-m-l+2|LSC(A, C)|$$

$$=2n+2|LCS(A, C)|-2|LCS(A, B)|$$

$$-2|LCS(B, C)|. \qquad (1)$$

Let s be the longest common subsequence of LCS(A, B) and LCS(B, C), and $|s|=p$. Note that

$$|LCS(A, C)\geq p \qquad (2)$$

since s is a common subsequence of A and C.

We now argue the Equation (1) is non-negative. Dividing Equation (1) by 2 and reorganizing the equation, we have

$$(n+|LCS(A, C)|)-(|LCS(A, B)|+|LCS(B, C)|)$$

$$=(n+|LCS(A, C)|)-(|s1|+|s2|+p+p) \qquad (3)$$

where s_1 and s_2 are the subsequences on LCS(A, B) and LCS(B, C), but not on LCS(B, C) and LCS(A, B) respectively. Note that both s_1 and s_2 are subsequences on B. Furthermore, the intersection between s_1 and s_2 must be empty, otherwise s will not be the longest common subsequence of LCS(A, B) and LCS(B, C). Then we have

$$|s_1|+|s_2|+p\leq n. \qquad (4)$$

By Equations (2) and (4), we have Equation (3) is greater than or equal to 0. The lemma follows.

3. Metric for Common Nodes

The metric D_{lcs} also contains information about the order of the nodes that were visited. We may want to know how many nodes are common in two navigation patterns without considering such ordering. If we only consider whether a node was visited or not the navigation pattern can be represented as a 0/1-bit string stored in an 1-D array of length N where N is the total number of nodes in the digraph.

Suppose A and B are two paths which respectively have m and n bit values 1 on the strings. We define the function C(A, B) to be the number of common positions that have bit value 1 in both A and B. The distance between A and B is then defined as

$$D_{common}(A, B)=1-\frac{C(A, B)}{\max(m, n)}.$$

Lemma 2. The distance function D_{common} is a metric.

Proof: only the triangle inequality is proved, because the other properties are trivial. Suppose that there are three paths A, B, and C and the number of positions having bit-value 1 are m, n, and l respectively. We only show the case that $D_{common}(A, B)+D_{common}(B, C)-D_{common}(A, C)>0$.

$$D_{common}(A, B)+D_{common}(B,C)-D_{common}(A, C)$$

$$=1-\frac{C(A,B)}{\max(m,n)}+1-\frac{C(B,C)}{\max(n,l)}-1+\frac{C(A,C)}{\max(m,n)}$$

$$=1+\frac{C(A,C)}{\max(m,l)}-1-\frac{C(A,B)}{\max(m,n)}-\frac{C(B,C)}{\max(n,l)} \tag{5}$$

To argue Equation (5) is greater than or equal to 0, let C(A, B), C(B, C), and C(A, C) be p_1+p, p_2+p, and p_3+p respectively where p is the number of common positions of A, B, and C having bit value 1. Consider two cases.

Case 1. If m or l is the largest among m, n, and l, let x=max (m, l). Equation (5) then becomes

$$1+\frac{p_3+p}{x}-\frac{p_1+p}{x}-\frac{p_2+p}{\max(n,l)}$$

$$=1+\frac{p_3}{x}-\frac{p_1}{x}-\frac{p_2+p}{\max(n,l)}$$

$$=x\cdot\max(n, l)+p_3\cdot\max(n, l)-p_1\cdot\max(n, l)-x\cdot p_2$$

$$-x\cdot p$$

$$\geq x\cdot\max(n, l)+p_3\cdot\max(n, l)-x\cdot p_1-x\cdot p_2-x\cdot p$$

$$=x\cdot\max(n, l)+p_3\cdot\max(n, l)-x\cdot(p_1+p_2+p)$$

$$\geq x\cdot\max(n, l)+p_3\cdot\max(n, l)-x\cdot n$$

$$\text{since } p_1+p_2+p\leq n$$

$$=\epsilon+p_3\cdot\max(n, l),\ \epsilon\geq 0 \text{ since } x\cdot\max(n, l)\geq xn$$

$$\geq 0.$$

Case 2. If n is the largest among m, n, and l, Equation (5) becomes

$$1+\frac{p_3+p}{\max(m,l)}-\frac{p_1+p}{n}+\frac{p_2+p}{n}$$

$$\geq 1+\frac{p_3}{\max(m,l)}-\frac{p_1}{n}-\frac{p_2+p}{n}$$

$$\text{since } \max(m, l)\leq n$$

$$=n\cdot\max(m, l)+n\cdot p_3-p_1\cdot\max(m, l)$$

$$-x\cdot p_2\cdot\max(m, l)-p\cdot\max(m, l)$$

$$=n\cdot\max(m, l)+n\cdot p_3-(p_1+p_2+p)\cdot\max(m, l)$$

$$\geq n\cdot\max(m, l)+n\cdot p_3-n\cdot\max(m, l)$$

$$\text{since } p_1+p_2+p\leq n$$

$$=n\cdot p_3$$

$$\geq 0.$$

4. Metric for the elapsed Time at Nodes

The elapsed time is the time that a student spends browsing a node. The time a student spends at a node can provide much information. For example, if student spends a long time on a specific node, this could mean that the student does not have enough background for the material in that node, or the material in that node is too difficult. That is, in a hypertext tutoring system, the elapsed time is an important factor in the analysis of learning patterns. Designing a metric for the elapsed time helps us analyze the learning patterns of students. We now show that we can define a metric for the elapsed time.

Suppose there are N nodes in the hypertext system and the elapsed time is given at each node. If a student has browsed a node more than once, the elapsed time is the accumulated time spent at the node and the elapsed time is 0 if the node has not been visited at all.

Let $A=a_1, a_2, ..., a_N$ and $B=b_1, b_2, ..., b_N$ be two navigation patterns. The time spent at nodes a_i and b_j are than denoted t_{ai} and t_{bj}. Since such time is very user-dependent, t_{ai} and t_{bj} cannot be used to define the metric directly. For example, reading speeds can differ greatly among students. We thus need to normalize the elapsed time. Let $t_{a_{total}}$ and $t_{b_{total}}$ be the total accumulated time for the learning paths A and B. The normalized elapsed time T_{x_i}, $x\in\{a, b\}$, is defined as

$$T_{a_i}=\frac{T_{a_i}}{t_{a_{total}}},$$

$$T_{b_i} = \frac{T_{b_i}}{t_{b_{total}}}.$$

The distance between two learning paths based on the elapsed time is given as

$$D_{time}(A, B) = \sum_{i=0}^{N-1} |T_{a_i} - T_{b_i}|.$$

Lemma 3. The distance function D_{time} is a metric.
Proof: We prove the triangle inequality. Suppose that we have 3 navigation patterns:

$A=a_0, \ldots, a_{N-1}$,

$B=b_0, \ldots, b_{N-1}$,

$C=c_0, \ldots, c_{N-1}$.

We show that $D_{time}(A, B)+D_{time}(B, C)-D_{time}(C, A)$ is greater than or equal to 0.

$$\begin{aligned}
&D_{time}(A, B)+D_{time}(B, C)-D_{time}(A, C)\\
&= \sum_{i=0}^{s-1} |T_{a_i} - T_{b_i}| + \sum_{i=0}^{s-1} |T_{b_i} - T_{c_i}| - \sum_{i=0}^{s-1} |T_{a_i} - T_{c_i}|\\
&=\{|T_{a_0}-T_{b_0}|+|T_{b_0}-T_{c_0}|-|T_{a_0}-T_{c_0}|\}+\ldots\\
&\quad+\{|T_{a_{s-1}}-T_{b_{s-1}}|+|T_{b_{s-1}}-T_{c_{s-1}}|-|T_{a_{s-1}}-T_{c_{s-1}}|\}\\
&\geq 0.
\end{aligned}$$

In order to record "noiseless" elapsed time, we need to define an upper bound and a lower bound for the time spent at a node. Very often a student leaves the computer while he (or she) is browsing a node or a student wants to revisit a node which has been browsed before. Such actions cause noises that may make the recorded time meaningless. Designing an upper bound should detect the abnormally long browsing time. A lower bound is also needed since the user s may want to go back to nodes traversed earlier. The time spent at the nodes between the current node and target node are meaningless to us. Hence, time spent on such nodes are eliminated by the lower bound. An elapsed time is recorded if it falls between the lower bound and the upper bound.

The above measurement gives the "static elapsed time". As mentioned earlier, the elapsed time is very student-dependent. Thus the bounds for students should be different as well. We propose the *justified bounds mechanism*, which collects elapsed time from the first several nodes and then modifies the lower bound and the upper bound.

At the very beginning, we set a static lower bound and a static upper bound. The bounds must be loose. And an initial student average elapsed time is set to be:

$$\frac{(\text{static lower bound} + \text{static upper bound})}{2}.$$

We define two coefficients α_{lo} and α_{up} as follows:

$$\alpha_{lo} = \frac{\text{static lower bound}}{\text{average time}},$$

$$\alpha_{up} = \frac{\text{static upper bound}}{\text{average time}}.$$

After students have browsed several (for instance 50) nodes, the average elapsed time may be changed. The new lower bound and upper bound are then modified, becoming:

modified lower bound
$=\alpha_{lo}\cdot$(new average elapsed time),

modified upper bound
$=\alpha_{up}\cdot$(new average elapsed time).

With the justified bounds mechanism, we can record elapsed time more accurately.

5. Metric for Results of Tests

Quizzes are way to evaluate the result of learning of students. Defining a metric based on scores of quizzes is helpful for classifying students according to the results of learning. If a node in a hypertext tutoring system is a test or a quiz, scores should be recorded in a node.

A metric for the scores of the tests will be helpful in classifying the students in terms of learning results. A score is a real number or an integer associated with the test node. If a student has not visited a test node, the score at that node is labeled "null". In designing the score attribute, we do not consider the order of the examinations that a student takes. Assume that the highest scores at all such nodes are the same (otherwise the scores can be normalized to be the same). The navigation patterns for the results of tests can be stored in an array of length

N' where N' is the number of test nodes. Each entry in the array is either a score or null. Suppose there are three learning paths A, B and C.

$$A = a_0, \ldots, a_{N'-1},$$

$$B = b_0, \ldots, b_{N'-1},$$

$$C = c_0, \ldots, c_{N'-1}.$$

Let s_{x_i} be the score of node x, $x \in \{a, b, c\}$. We define a constant τ which is greater than the highest score. The distance between s_{a_i} and s_{b_i}, denoted $S_{(a_i, b_i)}$, is defined as:

$$S_{(a_i, b_i)} = \begin{cases} |s_{a_i} - s_{b_i}| & \text{both } s_{a_i} \text{ and } s_{b_i} \text{ are not null,} \\ 0 & s_{a_i} = s_{b_i} = \text{null}, \\ \tau & \text{otherwise}. \end{cases}$$

The distance function between two navigation patterns regarding the results of the tests is then:

$$D_{score}(A, B) = \sum_{i=0}^{N'-1} S_{(a_i, b_i)}.$$

Lemma 4. The distance function D_{score} is a metric.

Proof: Only the triangle inequality

$$D_{score}(A, B) + D_{score}(B, C) - D_{score}(A, C) \geq 0$$

is proved. The proof proceeds by induction on n, the length of the navigation pattern. For n = 1, we consider three cases:

1. If $s_{a_0} = s_{c_0} =$ null. In this case, $D_{score}(A, C) = 0$ while $D_{score}(A, B)$ and $D_{score}(B, C)$ are τ or 0. We have $D_{score}(A, B) + D_{score}(B, C) - Dd_{score}(A, C) \geq 0$.
2. If exactly one of s_{a_0}, s_{c_0} is null, then $D_{score}(A, C) = \tau$. We may assume without loss of generality that s_{a_0} is null. The outcomes of $D_{score}(A, B)$ and $D_{score}(B, C)$ depends on s_{b_0}. If s_{b_0} is null then $D_{score}(A, B) = 0$ and $D_{score}(B, C) = t$. If s_{b_0} is not null then $D_{score}(A, B) = \tau$ and Dscore(B, C)=0. Both cases we have $D_{score}(A, B) + D_{score}(B, C) - D_{score}(A, C) \geq 0$.
3. If both s_{a_0} and s_{c_0} are not null we then have $0 < D_{score}(A, C) < \tau$. If s_{b_0} is null, then $D_{score}(A, B)$ and $D_{score}(B, C)$ are τ. If s_{b_0} is not null,

$$D_{score}(A, B) + D_{score}(B, C) - D_{score}(A, C)$$

$$= |s_{a_0} - s_{b_0}| + |s_{b_0} - s_{c_0}| - |s_{a_0} - s_{c_0}|$$

$$\geq 0$$

thus meeting the triangle inequality.

Assume that the triangle inequality holds for n=k. Let n=k+1. We have:

$$D_{score}(A, B) + D_{score}(B, C) - D_{score}(A, C) \tag{6}$$

$$= \sum_{i=0}^{k-1} S_{(a_i, b_i)} + \sum_{i=0}^{k-1} S_{(b_i, c_i)} - \sum_{i=0}^{k-1} S_{(a_i, c_i)}$$

$$+ S_{(a_k, b_k)} + S_{(b_k, c_k)} + S_{(a_k, c_k)}. \tag{7}$$

By the induction hypothesis, we have:

$$= \sum_{i=0}^{k-1} S_{(a_i, b_i)} + \sum_{i=0}^{k-1} S_{(b_i, c_i)} - \sum_{i=0}^{k-1} S_{(a_i, c_i)} = \epsilon \geq 0.$$

Equation (7) becomes:

$$\epsilon + S_{(a_k, b_k)} + S_{(b_k, c_k)} - S_{(a_k, c_k)}.$$

By arguments similar to the discussion where n=1, we can have:

$$S_{(a_k, b_k)} + S_{(b_k, c_k)} - S_{(a_k, c_k)} \geq 0.$$

Therefore the triangle inequality holds when n=k+1.

6. Combination of Metrics

Since the linear combination of metrics is still a metric, we can define new metrics by the combination of metrics defied above. For example, we can combine the two metrics $D_{lcs}(A, B)$ and $D_{score}(A, B)$ to obtain the new metric D,

$$D(A, B) = D_{lcs}(A, B) + D_{time}(A, B).$$

The metric D describes the similarity between two paths regarding results of tests, the nodes visited, and order of visited nodes. Others may want to adjust the metric to be:

$$D(A, B) = w_1 D_{lcs}(A, B)$$

$$+ w_2 D_{time}(A, B) + w_3 D_{common}(A, B),$$

where $w_i > 0$, $\Sigma wi = 1$ are the weights of each attribute. Due to the mathematical properties of metrics, we are able to take many factors into consideration (analysis) if these factors can be quantified through metrics.

V. Conclusions and Discussion

In this paper, we studied the question of how the define the similarity between navigation patterns in a hypertext tutoring system. The longest common subsequence and other attributes were used to determine the similarities. Two cases depending on whether the digraph representing the hypertext system was acyclic or not were discussed. For the cases where digraphs were acyclic, we proposed an efficient method to compute the longest common subsequence. The proposed method also has the advantage that the navigation patterns can be stored in the very compact form of 0/1 bit-strings, reducing the space required for database storage of navigation patterns. To tackle the general case where the digraph is not acyclic, we proposed several types of metric to define the similarities. After the metrics have been defined, the problem of determining the similarity of pairs of navigation patterns becomes a proximity problem [10, 14]. Furthermore, partitioning the students into groups (clusters) becomes possible after the metrics have been defined. This helps in analyzing learning patterns among students.

There is a problem with the metric approach. The cost of computing the distance between paths is high. Consider the metric D_{lcs}. Since a learning path is not obtained from an acyclic graph, the LCS must be obtained by dynamic programming. Although there are efficient clustering algorithms which can reduce the number of pairs of patterns involved in such computation, we still expect the computing time to be high since dynamic programming takes $\Theta(mn)$ time. A possible approach to solving this problem is to "contract" the digraph into an acyclic graph, i.e., merge several nodes and edges into a "supernode" to eliminate direct cycles. Then the algorithm stated in Section 3 may be applied to find a smaller set of similar paths. Finally, the metric D_{lcs} could be applied.

Another possible matching stratege might divide the matching process into more than one step. Taking our proposed metrics as an example, in the first step we found the 20 most similar paths by using a time metric, and in the second step we used the LCS metric to get the most similar paths among the 20 paths.

Regardless of the problem with computation cost, the metric approach is a general approach and it allows us to take many factors into consideration. The important task is to define factors in term of metrics. We have proposed some but not all metrics. There are still cases for which we do not know how to quantify the differences and are not able to define metrics. In using a hypertext system, one can browse text by opening two or more windows simultaneously. If the visiting order of nodes is not important, the metric D_{common} might be applicable, but some information seems to be missing. Another example is in diagnostic intelligent tutoring systems where there is a database for students' misconception patterns. The question is whether such information can be quantified. If we can quantify such information, we might be able to define a precise metric. We propose these as subjects for future work.

References

Aldenderfer, M., and Blashfield, R. "Cluster Analysis." Newbury Park, California: SAGE Publications. 1984.

Botafogo, R. A., and Shneiderman, B. "Identifying Aggregates in hypertext Structures," *ACM Hypertext '91 proceedings*, pp. 63-74.

Botafogo, R. A., Rivlin, E., and Shneiderman, b. "Structural Analysis of Hypertexts: Identifying Hierarchies and Useful metrics," *ACM Trans. on Information Systems*, Vol. 10 no. 2, April 1992, pp. 142-180.

Cormen, T. H., Leiserson, C. E., and Rivest, R. L., "Introduction to Algorithm," The MIT Press, pp. 314-320.

Fredman, M. L. "On Computing the Length of Longest Increasing Subsequences," *Discrete mathematics* 11, 1 (Jan 1975) 29-36.

Horowitz, E., Sahni, S., and Anderson-Freed, Fundamental of Data Structures in C, Computer Sicence Press, New York, 1993.

Marchionini, G. "Hypermedia and Learning: Freedom and Chaos," *Educ. Techno*l. 28, 11, 1988, pp. 8-12.

Marchionini, G., and Crane, G. "Evaluating hypermedia and learning: Methods and Results from Perseus Project," *ACM Trans. on Information Systems*, v.12 n.1, Jan 1994, pp. 5-34.

Nielsen, J. *Hypertext and Hypermedia* academic Press, New York. 1990.

Shamos, M. I., and Hoey, D. "Closest-point problems," *In Proceedings of the 16th IEEE Symposium on Foundations of Computer Science* Oct 1975. IEEE, New York, 1975. pp. 151-162.

Shasha, D., and Wang, T. -L. "New Techniques for Best-Match retrieval," *ACM Trans. on Information Systems*, Vol. 8, no. 2, April 1990, pp. 140-158.

Shore, A., and Daniel, D. "Enhancing Teacher utilization of Complex Instructional Systems," *Proceedings of Selected Research and Development Presentations at the Convention of the Association for educational Communications and Technology*, Feb '92.

Sleeman, D., and Brown, J. S. (Eds), "Intelligent Tutoring Systems," Academic Press, New York, 1982.

Smeaton, A. F., and Van Rijsbergen, C. J. "The nearest neighbor problem in information retrieval: An algorithm using upper bounds," *ACM SIGIR Forum 16*, 1981, pp. 83-87.

超文字系統中學習路徑的相似性

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摘　要

我們提出了一個好的方法來定義在超文件系統的相似性，這個工作的動機在於當學生使用超文件教學系統時定義他們之間學習路徑的相似性，最大相同子路徑和很多其他特性之差異被對應到一個實數以表示其相似性，我們證明了，如果超文件系統能夠被表示成一個非循環的有向圖，則最大相同子路徑能夠很快的被獲得；對於一般的例子來說有向圖是會有循環的，我們建議使用公制來定義相似性，釦制是基於最大相同子路徑及其他特性而被表示的，學生學習路徑則能夠藉由分群法中更進一步的應用來分析。

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Investigating the Nature and Development of Pre-Service Chemistry Teachers' Content Knowledge, Pedagogical Knowledge and Pedagogical Content Knowledge

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ABSTRACT

This study investigated the nature and development of content knowledge, pedagogical knowledge and pedagogical content knowledge of three pre-service chemistry teachers during one year of practicum course. Views toward pedagogical content knowledge in studies by Shulman (1986), Cochran et al. (1993), Lederman, et al. (1994), and Reynolds (1992) were applied as a research framework for this investigation. Qualitative data collection included semi-structured interviews before and after each teaching experience, classroom observation and assignment collection. Interviews addressed the subjects' views on chemistry and the topics they taught, their methods of transmitting content knowledge to students and their views on general pedagogy.

After taking one year of practicum course, pre-service chemistry teachers' views on chemistry became simpler and broader than before. On the other hand, their knowledge of pedagogy became more complicated, focusing more on students' characteristics and learning styles than before. Most of their pedagogical content knowledge included terminological explanations and usage of analogies. Toward the end of the study, the pre-service chemistry teachers started to link content and pedagogical knowledge in their concept of science teaching. Factors influencing these pre-service chemistry teachers' content knowledge, pedagogical knowledge and pedagogical content knowledge development were their reflection and action ability, real teaching experience and their preferences toward content, pedagogy and pedagogical content knowledge. Suggestions for future science teacher education are addressed in this study.

Keywords: Science teacher education, pedagogical content knowledge, content knowledge, pedagogical knowledge, professional development

I. Introduction

The goals of secondary pre-service science teacher education are to prepare future science teachers who are competent in both science content knowledge and science teaching ability. In order to cultivate future teachers' competence in these areas, science teacher education programs provide two categories of courses -- content courses and pedagogy courses. The general belief held by proponents of this design is that after taking these courses, the pre-service teachers will naturally integrate these two separate domains -- pedagogy and content, and fluently apply them to classroom teaching. However, during the past few years, science educators(Lederman, Gess-Newsome, & Latz, 1994; Gess-Newsome & Lederman, 1992; Lederman & Latz, 1993; Hoz, Tomer, & Tamir, 1990; Hashweh, 1987) have started to address the importance of both pre- and in-service science teachers' content and pedagogical knowledge, and how these areas of knowledge influence each other in their classroom teaching. These researchers also tried to answer the question of whether taking courses separately on content and pedagogy could naturally generate knowledge in content teaching.

The above research was mainly influenced by Shulman (1986, 1987), who advocated the importance of pedagogical content knowledge. He defined pedagogical content knowledge (PCK) as one form of content knowledge and proposed that it was subject-matter knowledge for teaching. It includes the presenting of science topics, analogies, elicitation, examples, explanations and demonstrations. In short, the teacher uses different ways to convey particular topics to a particular level of students. Grossman(1988) defined four essential elements of pedagogical content knowledge: (1) teachers' beliefs about particular grade levels, students and topics, (2) identifying students' preconceptions towards certain topics, (3) understanding a particular curriculum, including the connections between different subjects and within the same subjects, (4) understanding effective methods for presenting particular topics.

In describing the nature of pedagogical content knowledge, both Shulman (1987) and Kennedy (1990) described PCK as the mixing and blending of content and pedagogical knowledge, which is different from the knowledge of content and pedagogy held by teachers. However, other researchers (Cochran, 1991; Cochran, Deruiter, & King, 1993), using a constructivist perspective, argued with Shulman's compartmental nature of pedagogical content knowledge, which separated pedagogy and content knowledge. They believed that based on constructivism, teachers are active learners who try to learn how students construct learning. Thus, pedagogical content knowledge should be dynamic, constantly changing and evolving from pedagogy and content knowledge. Cochran, et al. substituted the concept of "pedagogical content knowing" for pedagogical content knowledge, and proposed that it integrated four domains of knowledge: subject matter, knowledge of pedagogy, knowledge of students and knowledge of environmental context. The more the pedagogical content knowledge is developed, the less distinction there is within these four domains of knowledge. Reynolds (1992) also defined PCK as the overlap of three domains of knowledge: content knowledge, general principles of teaching and learning, and general subjects/liberal arts.

Lederman and colleagues (Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1993) have done a series of studies on the nature and development of pre-service science teachers' knowledge structure of content and pedagogy. They concluded that pedagogical content knowledge was not separate from content knowledge and pedagogical knowledge. However, the longitudinal studies done by Lederman and his fellow researchers were primarily based on questionnaire and interview data. Thus real classroom observation is needed to illustrate the nature of pedagogical content knowledge.

In fact, the above argument regarding the nature of pedagogical content knowledge is based on two perspectives: the micro aspect, which is concerned with real classroom teaching and how teachers present content to their students (Shulman, 1986, 1987); and the macro aspect, which is concerned with the degree of overlap between the two main domains of knowledge--pedagogy and content (Cochran, 1991; Cochran, Deruiter, & King, 1993; Lederman, Gess-Newsome, & Latz, 1994; Reynolds, 1992).

In this research, PCK was defined using the two aspects mentioned above. From the micro aspect, that is, ways of presenting content knowledge to students' level, all forms of presenting content knowledge were counted as pedagogical content knowledge. This perspective was used to investigate the ways pre-service science teachers presented their content knowledge to students. From the macro aspect, PCK was the degree of integration of the teachers' content knowledge and pedagogical knowledge. Therefore, the more integration teachers had in their conceptualization of subject and pedagogy, the more developed their pedagogical content knowledge became.

The purposes of this study are (1) to investigate the nature and development of the content knowledge (CK), pedagogical knowledge (PK) and pedagogical content knowledge held by three pre-service chemistry teachers during one year of practicum course, and to identify the factors which influenced their knowledge development. The findings of this study can help science educators understand the nature and development of the content, pedagogy, and pedagogical content knowledge of pre-service teachers, elucidate the impact of science teacher preparation programs on their professional development, and suggest improvements to preparation programs for future science teachers.

II. Methods

The two-semester chemistry department practicum course was given to senior year pre-service teachers. The instructor, who was also the author, applied reflective teaching (Schön, 1986) and peer coaching methods in the course. Thus, each pre-service chemistry teacher had to practice two twenty-minute micro-teaching lessons with their classmates, self-analyze their teaching performance and be analyzed by their peer coaches. They were required to write lesson plans for the topics they taught, critique their own lesson plans and think of new ways to improve them after teaching.

In the second semester, each pre-service chemistry teacher had to go to a junior high school to teach two classes of physical science to eighth and/or ninth graders for one month. Each pre-service teacher was required to write journals focused on reflecting their teaching performance, and analyze their one-hour classroom teaching.

At the beginning of the semester, all pre-service chemistry teachers enrolled in the practicum course wrote essays on their views on chemistry and pedagogy. Among them, the three subjects selected in this study put a lot of effort into writing their assignments, were fluent in both verbal and written expression of their ideas, and were willing to participate in this one-year study. They also held different perspectives on pedagogy and content knowledge, thus providing a broad data base for answering the research questions.

Ah-Jan, Ah-Lin, and Ah-Sha were all chemistry major seniors enrolled at a normal university located in central Taiwan. They were all in the age range of twenty-two to twenty-three years old. Their GPAs were in the top 15% of their class, especially Ah-Lin, who had been the top student in his class for eight semesters. Half of the students enrolled in the chemistry department were self-supported. They were not obligated to teaching junior high school after graduation, and most of them planned to continue their studies in chemistry. The other half of the students were sponsored by the government, and thus had to become junior high school teachers after graduation.

Due to the exploratory nature of this study, a qualitative method with a case-study design (Bogdan & Biklen, 1992) was used to provide more flexibility and in-depth views in answering research questions. The study was conducted in the practicum course offered by the chemistry department. Semi-structured interviews from the Lederman & Latz (1993) study were conducted to survey the subjects' knowledge of chemistry and pedagogy as defined by the macro-aspect perspective. The following are examples of interview questions:

1. What do you think of when you think of "teaching"? (you can draw diagrams or just describe what you think.)
2. Have you used the method mentioned above in conceptualizing your teaching?
3. What do you think of when you think of "chemistry"? What's the connection between chemistry and other disciplines?
4. Have you used the method mentioned above when you conceptualize chemistry?
5. In an ideal situation, how will you teach physical science?
6. What do you expect your students to learn from their junior high school physical science course?
7. In terms of chemistry and pedagogy, what kinds of changes have you made? What caused the changes?

All the figures listed in the section of findings and discussion were based on this part of the findings. The rationale behind these questions was to provide opportunities for subjects to freely express their knowledge of content and pedagogy without any prompting from the researchers. During the three pre-service chemistry teachers' two micro-teachings in the first semester and one-month field experience where they taught two physical science units, the author and other researchers conducted semi-structured interviews before and after their teaching performance. This part of the data was used to answer questions on the subjects' pedagogical content knowledge from the micro-aspect perspective.

Examples of interview questions are listed below:

Before teaching
1. Could you describe all the knowledge you have on the topic you are teaching?
2. Which part of the knowledge you presented above would you teach to your students?
3. How will you present the knowledge you have to your students?
4. In this topic, which part would cause students to have misconceptions?
5. How will you teach the concepts which students have difficulty learning (or which cause misconceptions)?
6. What are your teaching goals in this topic?

After teaching
1. Has your knowledge of this topic changed? What caused the changes?
2. What changes will you make on the topic you just taught?
3. What are the strengths and weaknesses of your teaching performance?
4. What kinds of changes will you make the next time you teach?

Semi-structured interviews were conducted to help researchers collect similar data across different subjects, and also to allow them to collect in-depth data from those subjects. Data from informal interviews after each classroom observation were also collected to supply classroom observation information and support formal interview data. Other sources of data included classroom observations during two micro-teaching sessions, three student-teaching sessions and written document such as the journals, lesson plans and the subjects' assignments for the practicum course.

After transcribing all the interview data, each subject's data were analyzed separately by the author and other researchers. The researchers discussed the findings to obtain consensus. When the researchers held different perceptions of the data, they re-analyzed the data and again discussed to reach an agreement on the findings. After analyzing each case, the author compared and contrasted the findings from the three subjects with those of their classmates, and also revised previous explanations of the data in order to encapsulate the findings across the three subjects.

III. Findings & Discussion

1. Description of The Subjects

Ah-Jan and Ah-Sha were self-supported. Ah-Jan's goal was to go abroad after graduation to earn a doctoral degree in chemistry. Ah-Sha had decided to become a teacher since enrolling at the college. She wanted to be a junior high school teacher after graduation. As a government-sponsored student, Ah-Lin knew he was obligated to teach in a junior high school after graduation, even though he would have liked to continue with his studies in chemistry.

Ah-Jan was an energetic, enthusiastic and creative student. She likes laboratory work very much and has joined a laboratory research team for two years. Although Ah-Jan did not plan to teach in a high school, she was very earnest in preparing all the materials and assignments in her practicum course. In preparing and reflecting on her teaching, she liked to think of many ways of transmitting concepts to her students.

Ah-Sha was calm and conservative, with a motherly personality. Among her classmates, she was one of the few who were self-composed and was the sternest during her teaching. In every interview, most of her responses addressed students' needs, motivations, morals and behavior. Ah-Sha liked to think of ways to improve her teaching, but ultimately, because of her conservatism, she did not change much.

Ah-Lin was a typical well-behaved and hard-working student, with a shy but rigorous personality. He tended to be textbook oriented, relying heavily on book information, and was the only subject who frequently addressed subject-matter knowledge. However, having too little knowledge of pedagogy, especially knowledge of students, has caused him many problems in teaching in junior high school.

The findings reported present the culmination of various subjects and analysis, and have been organized to answer the initial research questions.

2. The Nature and Development of Pre-Service Chemistry Teachers' Content Knowledge

Interviews and written responses indicated that pre-service teachers have not processed or conceptualized the chemistry knowledge they have learned in college. Although their responses ranged from the four fundamental chemistry courses-- "physical, organic, analytical and inorganic chemistry" to a list of additional topics and courses taken, to their preferences in the content courses they took at the university, all the preservice teachers were very surprised by the question: "what do you think of chemistry?". In the beginning of the semester, their responses were typically "I have never thought about that before" and they tried to think of responses during the interviews. Although they had one year to think about the question: "What is chemistry?" and respond to the author, their content knowledge was still simply a list of terms, topics and courses they had learned from the university, thus supporting the findings of Gess-Newsome (1993), Lederman & Latz (1993). The differences among the three subjects' views on content knowledge were revealed after several in-depth interviews. These different views on content were mainly influenced by their preferences when viewing the nature of chemistry. Among them, Ah-Jan was the only teacher who cared about using laboratory activities to explore chemistry knowledge, an approach called "syntactic knowledge structure" and advocated by Shulman (1986, 1987). Ah-Lin concentrated on the discipline structure of chemistry. Ah-Sha did not show any interest in thinking about the nature of the discipline of chemistry. She was more concerned with how to introduce chemistry to students and layman. Figure 1 shows Ah-Jan's concept of chemistry at the beginning of the study: lab equipment (funnel, beaker, flask, etc.) represent using the lab to explore the nature of the world and to improve our living environment. Chemistry also integrated with physics, history, mathematics, and other areas.

As mentioned before, Ah-Jan liked laboratory activities. Thus, in addition to reflecting her perceptions toward the nature of chemistry, her description of chemistry (see Fig. 1) also included laboratory equipment.

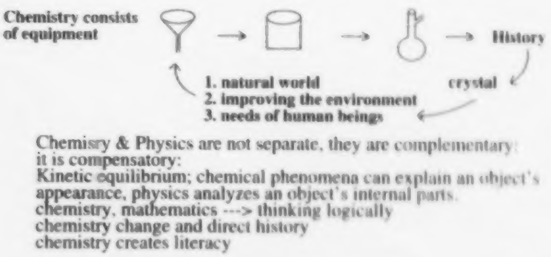
Chemistry consists of equipment
History
crystal
1. natural world
2. improving the environment
3. needs of human beings
Chemisry & Physics are not separate, they are complementary;
it is compensatory:
Kinetic equilibrium; chemical phenomena can explain an object's
appearance, physics analyzes an object's internal parts.
chemistry, mathematics ---> thinking logically
chemistry change and direct history
chemistry creates literacy

Fig. 1. Ah-Jan's Original CK Diagram.

Ah-Lin was the only student who tried very hard to explain the discipline structure using what he had learned from college textbooks. Despite his efforts, his responses to the author were simply additional topics he had learned from content classes.

In describing their content knowledge of the topics they were teaching, the pre-service chemistry teachers were inclined toward hierarchy-like knowledge structures. These knowledge structures primarily consisted of the logical sequence of concepts covered in junior high school physical science textbooks, with some advance concepts covered in high school and college chemistry courses. Some examples from their lesson plans are listed in Fig. 2, 3, and 4:

The above findings were supported by Tuan, Chiang and Lee's (1992) study on a class of preservice chemistry teachers' pre-activity thinking, which was mainly concerned with the organization and sequence of science concepts needed to be taught.

As Ah-Jan and Ah-Lin mentioned, this kind of hierarchy-like content knowledge structure could help them and the students organize the content in a meaningful and efficient way. Most

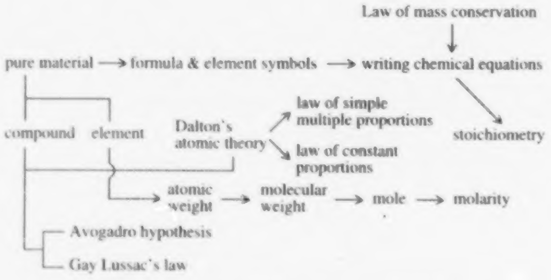
Law of mass conservation
pure material
formula & element symbols
writing chemical equations
compound
element
Dalton's atomic theory
law of simple multiple proportions
law of constant proportions
stoichiometry
atomic weight
molecular weight
mole
molarity
Avogadro hypothesis
Gay Lussac's law

Fig. 2. Ah-Lin's CK Diagram for Ch. 8.

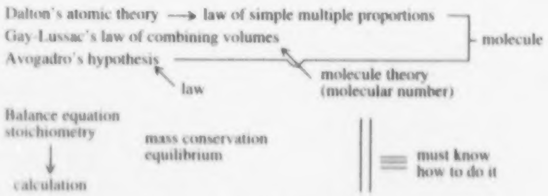
Dalton's atomic theory
law of simple multiple proportions
Gay-Lussac's law of combining volumes
Avogadro's hypothesis
molecule
law
molecule theory (molecular number)
Balance equation stoichiometry
calculation
mass conservation equilibrium
must know how to do it

Fig. 3. Ah-Jan's CK Diagram for Ch. 8.

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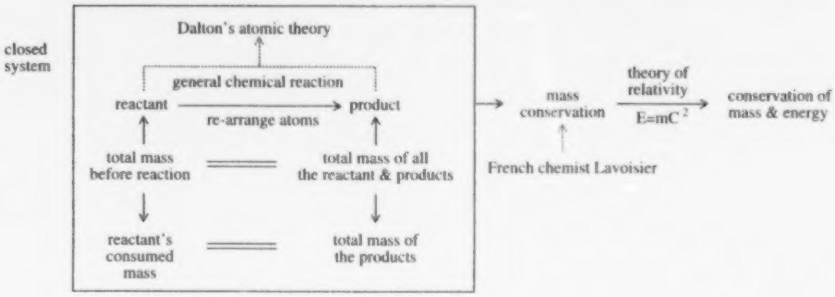
closed system
Dalton's atomic theory
general chemical reaction
reactant
re-arrange atoms
product
total mass before reaction
total mass of all the reactant & products
reactant's consumed mass
total mass of the products
mass conservation
French chemist Lavoisier
theory of relativity
E=mC²
conservation of mass & energy

Note: ... added after teaching

Fig. 4. Ah-Sha's CK Diagram for Ch. 7-5.

of the Taiwanese pre-service science teachers preferred an organized and systematic way of presenting their content knowledge and most of the students were also educated in this format.

Toward the end of the year, the terms and topics listed in the teachers' content knowledge structure became simpler, but these terms and topics also became more related to other disciplines and daily life (See Fig. 5, 6). The pre-service chemistry teachers started to integrate chemistry with the goals of junior high school physical science addressing daily phenomena within the students' living environment (see Fig. 5, 6). These findings also support Lederman & Latz's (1993) study of several American physical science teachers' content knowledge development.

3. The Nature and Development of Pre-Service Chemistry Teachers' Pedagogical Knowledge

At the beginning of the study, in responding to the question of what pre-service teachers thought of pedagogy, all the subjects gave a similar explanation that pedagogy is "teaching and learning", and constituted all the activities and communication between students and the teacher. Some examples (Fig. 7 and two excerpts) listed below illustrate the three subjects' original pedagogical knowledge:

On examining similar explanations among the subjects, the author found that in Chinese, "pedagogy" included "teaching" and "learning". This Chinese etymology influenced all the subjects in their usage, concepts and definitions of pedagogy at the beginning of the study. However, when the researchers asked them to describe in detail the meaning of "teaching" and "learning", they could not give very specific explanations.

It seems that the pedagogical knowledge of

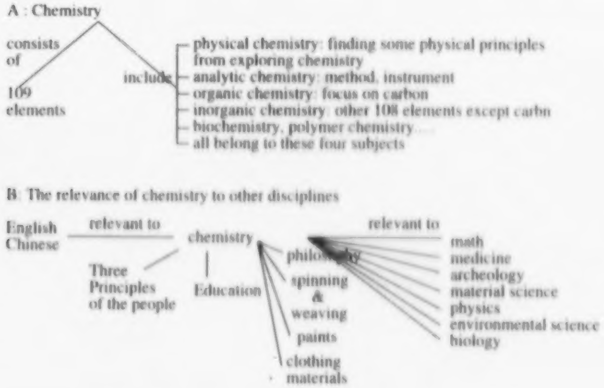
A : Chemistry
consists of
109 elements
include
physical chemistry: finding some physical principles from exploring chemistry
analytic chemistry: method, instrument
organic chemistry: focus on carbon
inorganic chemistry: other 108 elements except carbn
biochemistry, polymer chemistry......
all belong to these four subjects
B: The relevance of chemistry to other disciplines
English
Chinese
relevant to
chemistry
Three Principles of the people
Education
philosophy
spinning & weaving
paints
clothing materials
relevant to
math
medicine
archeology
material science
physics
environmental science
biology

Fig. 5. Ah-Lin's Final CK Diagram.

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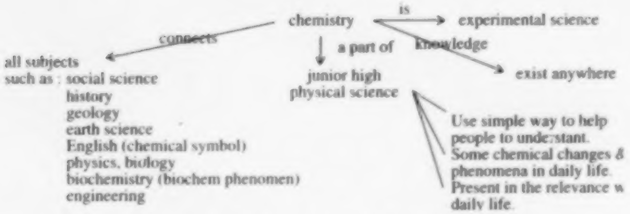

chemistry
is
experimental science
connects
a part of
knowledge
exist anywhere
all subjects
such as : social science
history
geology
earth science
English (chemical symbol)
physics, biology
biochemistry (biochem phenomen)
engineering
junior high
physical science
Use simple way to help
people to unde:stant.
Some chemical changes &
phenomena in daily life.
Present in the relevance w
daily life.

Fig. 6. Ah-Sha's Final CK Diagram.

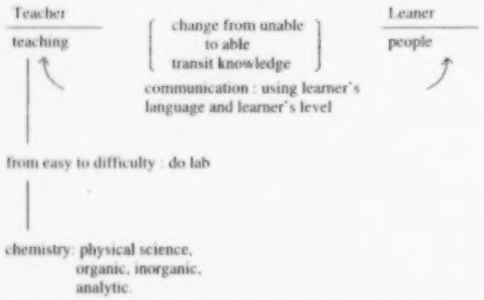
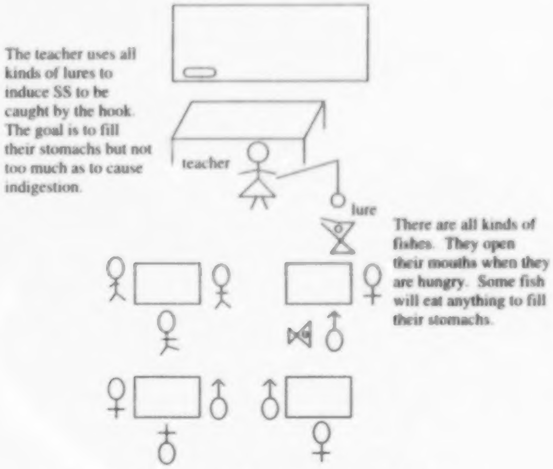

Teacher
teaching
change from unable
to able
transit knowledge
Leaner
people
communication : using learner's
language and learner's level
from easy to difficulty : do lab
chemistry: physical science,
organic, inorganic,
analytic.

Fig. 7. Ah-Sha's Original PK & CK Diagram.


The teacher uses all
kinds of lures to
induce SS to be
caught by the hook.
The goal is to fill
their stomachs but not
too much as to cause
indigestion.
teacher
lure
There are all kinds of
fishes. They open
their mouths when they
are hungry. Some fish
will eat anything to fill
their stomachs.

The teacher needs to pay attention in raising the fries, choosing the fishpond, adjusting temperature, and protecting them.

Fig. 8. Ah-Jan's Final PK Diagram.

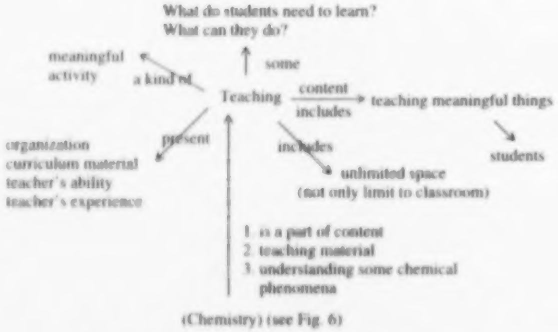

What do students need to learn?
What can they do?
some
meaningful
activity
a kind of
Teaching
content
includes
teaching meaningful things
students
present
organization
curriculum material
teacher's ability
teacher's experience
includes
unlimited space
(not only limit to classroom)
1. is a part of content
2. teaching material
3. understanding some chemical
phenomena
(Chemistry) (see Fig. 6)

Fig. 9. Ah-Sha's Final PK Diagram.

pre-service teachers' generally consisted of abstract principles and forms. These findings were unlike Lederman, Gess-Newsome, & Latz's (1994) findings on American pre-service science teachers who had more concrete formulations of their pedagogical knowledge than their Taiwanese counterparts.

Toward the end of the study, when asked about their knowledge of pedagogy, the subjects were more elaborate and described teaching in more specific detail (see Fig. 8, 9, and 10). At that time, they were more inclined toward using case examples (Shulman, 1986) to present their pedagogical knowledge. Ah-Jan even used metaphors to present her knowledge of pedagogy. As Tobin (1992, 1993) indicated, teachers' knowledge of teaching was stored in the form of beliefs, metaphors and images. The subjects attributed more responsibilities to teachers and also added many components relating to students' learning characteristics and habits to their pedagogical knowledge. Besides the above components, they also added issues relating to the school facility and environment. These findings are supported by Gess-Newsome & Lederman's (1993) and Lederman & Latz's (1993) findings on the pedagogical knowledge development of pre-service science teachers.

4. The Nature and Development of Pre-Service Chemistry Teachers' Pedagogical Content Knowledge

Data analysis based on classroom observa-

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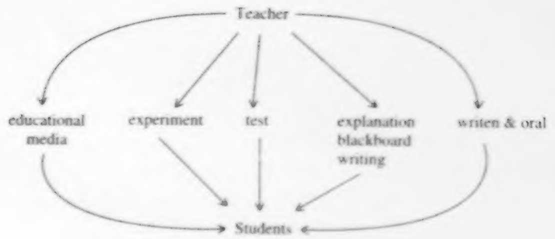

Fig. 10. Ah-Lin's Final PK Diagram.

tions and interviews concluded that Ah-Lin, Ah-Jan, & Ah-Sha's typical ways of presenting content were simply introducing concepts, explaining the definition of concepts, applying concepts to daily life events and/or calculation problems. The differences among the three subjects were that Ah-Lin used most of his time to define concepts to his students, while both Ah-Jan and Ah-Sha preferred to use daily life examples and/or analogies. Ah-Jan typically liked to use demonstrations or conduct lab activities to facilitate the students' learning of new concepts. For instance, Ah-Jan used lab activities to show students how copper was electroplated with nickel, and afterward explained to the researcher:

> I showed the students, and then they thought about whether they could electroplate a five-,ten-,or fifty-dollar coin, and see and discuss the difference...

The kinds of examples and analogies used during their teaching are listed:

> A mole is a counting unit of atoms just as a dozen is a counting unit of eggs or pencils
> A chemical reaction is a process of rearranging atoms but the total atoms and mass do not change. It is like a red pen and a black pen:
> red cap+black cap--->black cap+red cap
> red pen black pen red pen black pen

One feature of pedagogical content knowledge defined by Shulman(1986) is that teachers can identify and overcome students' misconceptions. However, this study found that the subjects were lacking in this aspect of pedagogical content knowledge because they were unaware of their students' misconceptions. Similar findings were also found in Marks' (1990) study. However, based on the subjects' previous learning experiences, as well as the students' verbal and nonverbal responses in class and their test results, the pre-service teachers were aware of students' learning difficulties. Tuan(1994) and Fong & Tuan (1993) found that pre-service chemistry teachers used their own learning experiences as a guideline to predict students' learning difficulties. Unfortunately, the lack of a substantial teaching repertoire, especially in strategies for conceptual change, limited these pre-service teachers to the use of slow-paced repetition to re-teach their pupils. One example shows how Ah-Sha overcame a learning difficulty of her students:

> For instance, they did not know how to calculate the molecular weight of glucose, so I wrote down the method step by step. In glucose, there are 6 C 12, 12 H1. Using this method step by step to calculate the molecular weight of glucose, then calculate the mole of glucose.

Westerman (1991) and Tuan (1994) concluded that the lack of teaching repertoire in the beginning teachers' schema impeded them in finding new ways to improve their teaching performance.

After reflecting on their classroom teaching performance, the pre-service chemistry teachers would address ways to motivate students' interests in learning, and discuss various analogies and examples that could be used in helping students understand concepts. During the study period, these pre-service chemistry teachers did not change their teaching performance much, but their awareness could help them address the importance of pedagogical content knowledge.

As Cochran, et al. (1993), Lederman & Latz (1993), and Reynolds(1992) pointed out, as a teacher merges his/her content and pedagogical knowledge, pedagogical content knowledge develops. From the macro point of view, at the end of the practicum course, the pre-service science teachers started to link content knowledge and pedagogical knowledge in conceptualizing science teaching.

Among the three subjects, Ah-Sha was the only one who had been conceptualizing chemistry content as a part of teaching. Therefore, from the beginning (see Fig. 6) to the end (see Fig. 9) of the practicum course, she integrated chemistry and teaching. The other two subjects-- Ah-Lin and Ah-Jan, rarely connected pedagogy and chemistry at the beginning of the course. However, toward the end of the study, when the researchers asked for their responses regarding chemistry and pedagogy, they started to become aware that these two separate disciplines had some connections.

5. Factors Influencing Pre-Service Chemistry teachers' Content Knowledge, Pedagogical Knowledge, and Pedagogical Content Knowledge Development

There are several factors influencing the three pre-service chemistry teachers' content knowledge, pedagogical knowledge, and pedagogical content knowledge development. This section will discuss each of the factors in the following paragraph.

(1) The pre-service chemistry teachers' reflection ability and commitment to make changes influenced their content, pedagogical and pedagogical content knowledge development.

Reflection ability in this study is defined as the teachers' ability to review their actions and evaluate whether their existing actions and knowledge were problematic, thus prompting them to find out new solutions for solving problems (Schön, 1986). Among the three subjects, Ah-Jan had the strongest reflection ability. She liked to review her teaching and try out new ways of teaching. Therefore in most of her informal interviews, she addressed her different teaching strategies and evaluated the success of her teaching. Her problem-solving skills were also strong in that she could identify problems and tried to solve the teaching problems she encountered. During the year-long investigation, Ah-Jan consistently reviewed and revised her knowledge of content, pedagogy and pedagogical content knowledge.

Ah-Sha was also proficient in identifying problems faced in the classroom and talked about many ways of solving the problems or improving upon her teaching. In every discussion with her about how to improve classroom teaching, she would think of many possibilities. However, she would become worried that the new methods would either disturb classroom discipline or require too much effort and that the existing system would have difficulty accepting the changes. Thus, her conservative personality and unwillingness to commit herself to change kept her using the same strategies in her classroom teaching, and she discussed similar pedagogical knowledge and content knowledge throughout her teaching.

Ah-Lin always concentrated on his content knowledge and was unaware of problems in his teaching. In discussing with him about improving his teaching, he always thought that teaching well-organized content information to students was important. If students did not learn well or understand the materials, he blamed them for being lazy and not studying hard. He did not know much about the students' characteristics, which impeded him in solving the problems and improving his teaching. This lack of ability in identifying problems also impeded Ah-Lin in his pedagogical knowledge and pedagogical content knowledge development.

It was only toward the end of the study that Ah-Lin started to realize that using simple content knowledge and analogies helped students in their understanding.

> Researcher: What kinds of changes did you make during the field-based practicum?
> Ah-Lin: I realized the importance of lab activities. I used to use too much jargon for the students to understand. This is not good for the students. I hope I can use more vivid ways to teach, such as using demonstrations or lab activities to impact them.

(2) The real classroom context that pre-service teachers were involved in during field-based experience facilitated their content knowledge, pedagogical knowledge and pedagogical content knowledge development.

As previously mentioned, all pre-service chemistry teachers enrolled in the practicum course were required to teach in two different contexts: a micro-teaching context and an actual classroom setting. The three subjects and their classmates all mentioned that the micro-teaching experience was a very "fake" situation where all their classmates had to act like junior high school students. However, these "fake" students were too advanced to be treated as real junior high school students. The three subjects and most of their classmates' reflection on their micro-teaching was centered on their own performance and competence, including such aspects as whether they spoke too fast, the legibility of their handwriting and whether their content knowledge would be challenged by their peers. However in their real classroom teaching, these pre-service chemistry teachers quickly became student oriented, focusing on students' responses, reactions and motivations. They became motivated in finding alternative ways of presenting content to their pupils, in re-thinking the goals of the physical science curriculum and the teacher's role. Thus, the real classroom context provided a dynamic interaction between the teacher and students, and helped the pre-service chemistry teachers develop their content knowledge, pedagogical knowledge and pedagogical content knowledge.

(3) The subjects' personal preferences in the different domains of knowledge influenced their content knowledge, pedagogical knowledge and pedagogical content knowledge development.

As previously mentioned, Ah-Lin was the subject who cared the most about content. Thus most of his thinking focussed on the structure of chemistry discipline and the kinds of content knowledge that students needed to know. Unfortunately, Ah-Lin did not have any affinity for pedagogical knowledge, thus impeding him in the development of his knowledge of pedagogy and pedagogical content. On the other hand, Ah-Sha was the subject who was most concerned with pedagogical knowledge. Throughout the study, she expressed concern about the students' and teacher's roles. However, her inadequate thought concerning content knowledge limited her in her development of content knowledge and pedagogical content knowledge. Ah-Jan was the only pre-service teacher whose preferences were equally distributed over the three domains of knowledge-- content, pedagogy, and pedagogical content knowledge. Thus her development of these knowledge domains was better and quicker than the other two subjects.

IV. Conclusions and Recommendations

The findings in this study illustrated that the pre-service chemistry teachers' content knowledge structure was in the form of a few terminologies and topics related to the courses they took in college, thus supporting the study by Gess-Newsome & Lederman (1993), Lederman & Latz (1993). Although these pre-service teachers had studied chemistry for four years, they did not conceptualize what they learned in the content courses, nor did they transfer content knowledge learned in college to junior high school science teaching. In fact they only used fragmentary factual knowledge learned from college courses to conceptualize and explain the topics they were teaching in junior high school physical science. Basically, when in a teaching context, they still relied heavily on the junior high school physical science textbooks instead of relying on their content knowledge to conceptualize and evaluate the content topics. The substantial and syntactic knowledge of subject discipline advocated by Shulman (1986) was not found in the three subjects.

In conceptualizing each topic, the pre-service chemistry teachers had a more hierarchy-like content structure. However, from a holistic viewpoint, this structure did not integrate with their content knowledge. Toward the end of this study, for practical reasons, the three pre-service chemistry teachers thought about the purpose of content knowledge and its usefulness to their students. As supported by other studies (Gess-Newsome & Lederman, 1993; Lederman & Latz, 1993), the subjects' chemistry knowledge structure became simpler and broader, and more related to the goals of junior high school physical science textbooks.

In the beginning, the pedagogical knowledge structure among the pre-service chemistry teachers was mainly focused on the interpretation of the term "teaching" and a few principles of teaching. Toward the end of study, their pedagogical knowledge structure became more elaborate, especially those components pertaining to students. This change might illustrate the influence of real classroom experience, which helped pre-service chemistry teachers construct increasingly elaborate knowledge of the aspects of teaching-- both the teacher and the student aspects. The sources of the pre-service chemistry teachers' pedagogical knowledge were mainly from their personal experiences as students or from interactions with their classroom students, with only a few based on their college educational courses.

Toward the end of the study, the pre-service chemistry teachers started to link pedagogy and content knowledge in their concept of teaching. According to the view of Cochran, Deruiter, & King (1993), and Reynolds (1992), and Lederman, Gess-Newsome, & Latz (1994) this change can be considered pedagogical content knowledge development. However, from the micro point of view suggested by Shulman(1986), the pre-service chemistry teachers used similar teaching strategies to introduce concepts to students. However, they lacked sufficient teaching repertoire, especially in the various areas of conceptual change teaching strategies which use analogies and examples to present concepts. Similar findings were also found in other studies (Clermont, Borko, & Krajack, 1994; Tuan, 1994; Westerman, 1991).

The factors influencing these pre-service chemistry teachers' content knowledge, pedagogical knowledge and pedagogical content knowledge development included their reflection and action ability, real classroom teaching context and their preferences in the different domains of knowledge. The last factor has been supported by Gudmundsdottir(1990), who addressed the importance of teachers' values in influencing their pedagogical content knowledge development. This values issue needs to be further addressed in the future.

Suggestions for science teacher education are as follows:

(1) Science educators should encourage pre-service science teachers to conceptualize the topics they need to teach, including the goals of the topic they are teaching, both important and peripheral concepts related to the topic and the kinds of concepts needed to be taught.

(2) Science educators should discuss with pre-service teachers various ways of presenting their understanding of the content to the pupils, such as by using analogies and examples, and should discuss the students' learning difficulty in particular topics.

(3) Science course instructors should address the importance and meaning of substantial and syntactic knowledge of the subject discipline with pre-service teachers instead of requiring them to simply memorize fragmented factual knowledge.

(4) The pre-service teachers' reflection ability is the factor which most influenced their pedagogical content knowledge development. Thus science educators should provide opportunities for pre-service teachers to reflect and improve on their teaching performance.

(5) For selecting proficient science teachers, we need to design valid and reliable instruments to assess beginning science teachers' reflection and action ability and their preferences in content, pedagogy, and pedagogical content knowledge.

Acknowledgments

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References

Bogdan, R. C. & Biklen, S. K. (1992). *Qualitative Research for Education*, 2nd Ed. Allyn and Bacon.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching*, *31*(4), 419-441.

Cochran, K. F. (1991). Pedagogical content knowledge: Teachers' transformations of subject matter. *NARST Newsletter*, September, No. 27. 7-10.

Cochran, K. F., Deruiter, J. A., & King, R. A. (1993). Pedagogical content knowing: an integrative model for teacher preparation. *Journal of Teacher Education*, *44*(40), 263-272.

Fong, H. L. & Tuan, H. L. (1993). Pre-service chemistry teachers' thinking during the micro-teaching context--a case study. *Conference Proceeding of the 1993 Chinese Science Education*.

Gess-Newsome, J. K. & Lederman, N. G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A yearlong assessment. *Science Teacher Education*, *77*(1), 25-43.

Grossman, P. L. (1988). *A study in contrast: Sources of pedagogical content knowledge for secondary English*. Unpublished doctoral dissertation, Stanford University, Stanford.

Gudmundsdottir, S. (1990). Values in pedagogical content knowledge. *Journal of Teacher Education*, May-June, *41*(3), 44-52.

Hashweh, M. Z. (1987). Effects of subject-matter knowledge in the teaching of biology and physics. *Teaching and Teacher Education*, *3*, 109-120.

Hoz, R., Tomer, Y., & Tamir, P. (1990). The relations between disciplinary and pedagogical knowledge and the length of teaching experience of biology and geography teachers. *Journal of Research in Science Teaching*, *27*, 973-985.

Kennedy, M. M. (1990). *Trends and issues in teachers' subject matter knowledge*. Washington, DC: ERIC Clearinghouse on Teacher Education and the American Association of Colleges for Teacher Education.

Lederman, N. G. & Latz, M. (1993). Emergence and

Interactions of knowledge structures in the pre-service teacher. Paper presented at the Annual meeting of the National Association for Research in Science Teaching. Atlanta, Georgia.

Lederman, N. G., Gess-Newsome, J. & Latz, M. S. (1994). The nature and development of pre-service science teachers' conceptions of subject matter and pedagogy. *Journal of Research in Science Teaching*, *31*(2), 129-146.

Marks, R. (1990). Pedagogical content knowledge: From a mathematical case to a modified conception. *Journal of Teacher Education*, *41*(3), 3-11.

Reynolds, A. (1992). What is competent beginning teaching? A review of the literature. *Review of Educational Research*, *62*(1), 1-35.

Schön, D. A. (1986). Educating the Reflective Practitioner. Jossey-Bass, Inc, Publishers.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(1), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1-22.

Tobin, K. (1992, April). *Conceptual change, teacher education, and curriculum reform*. Paper presented at the annual meeting of the American Educational Research Association, San Franciso.

Tobin, K. (1993). Constructivist perspectives on teacher learning. In K. Tobin (Ed.), *Practice of constructivism in science education* (pp. 215-226). Washington, DC.: AAAS press.

Tuan, H. L. & Chiang, W. H. & Lee, C. K. (1992) Pre-service chemistry teachers' thought process during micro-teaching experience. Proceeding of 1992 Chinese Science Education conference, 460-480.

Tuan, H. L. (1994). Pre-service chemistry teachers' thoughts toward teaching--A case study. *Chinese Journal of Science Education*, *2*(2), 115-141.

Westerman, D. A. (1991). Expert and novice teacher decision making. *Journal of Teacher Education*, *42*(4), 292-305.

探究職前化學教師學科知識、教學知識、與學科教學知識的本質與發展

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摘　要

本研究旨在探求三位職前化學敎師在大四一年實習課期間，其學科知識、敎學知識與學科敎學知識之本質與發展。Shulman (1986)，Cochran, et al (1993)，Lederman, et al (1994)與Reynolds (1992)等學者，對學科敎學知識的看法將作爲本研究的理論架構。本研究藉每次敎學前後對個案進行的半結構晤談、課室觀察，個案所撰寫之敎案與個案及學生之相關作業等途徑從事資料收集。晤談的重點包括個案對化學和其所敎授單元的觀點、如何將學科知識傳達給學生以及對一般敎學知識的看法。研究結果顯示在一年的研究期間，個案敎師對於化學領域內涵的描述越趨精簡，但是對於思考化學與其它學科領域的聯結度增加。敎學知識較一年前複雜，且著重在學生的特質和學習特色。至於個案的學科敎學知識則包含了名詞釋義和類比的引用。在研究的後期，個案敎師已能將學科知識與敎學知識二者納入其敎學考量之中。職前化學敎師學科知識、敎學知識與學科敎學知識發展之因素，包括敎師本身的反省和實踐能力，實際的課室敎學經驗，和敎師本身對學科、敎學與學科敎學知識的偏好等。有關對科敎師資培育之建議在本文中亦有論述。

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